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Calculation of Plate Temperatures in A Mk 4 LEU Fuel Element

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October 1991

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Second Edition 1991

CALCULATION OF PLATE TEMPERATURES IN A MK 4 LEU FUEL ELEMENT.

Karsten Haack

Abstract. A calculation method for estimating the axial temperature distributions of each of the 26 fuel elements of the DR 3 core is described and demonstrated. With input data for fuel element power, D_2O outlet temperature and main D_2O circulator combination, a computer code calculates all important temperatures in the fuel element.

Preface to Second Edition Oct. 1991

The second edition is based on the more reliable thermophysical heavy water properties made available by the investigations of Professor J. Bukovsky (Ref. 2).

The values in table 1 are replaced and a new set of fuel element temperature curves is enclosed as an example of the temperature distributions in a low enriched uranium (19,8% ^{235}U as U_3Si_2)core.

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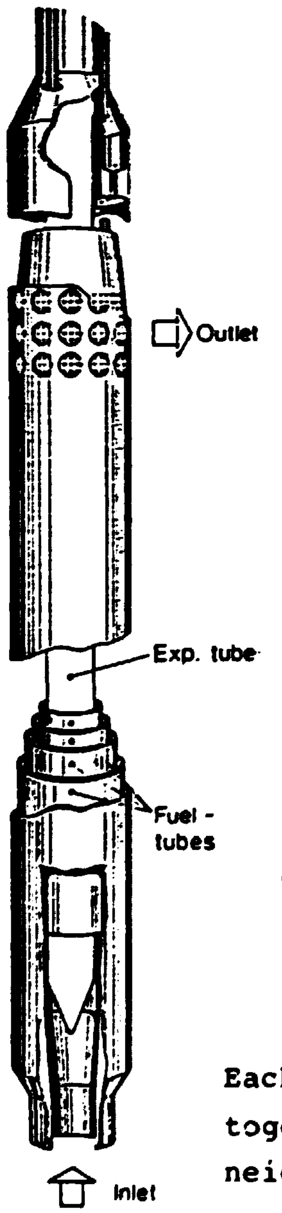
LIST OF CONTENTS PAGE

Introduction

In order to provide a means of compensation for avoiding reduction of the thermal neutron flux densities in the core positions of DR 3 while converting from highly enriched to low enriched uranium, application to the danish authorities has been made for upgrading the reactor power level.

This application involves a recalculation of the temperature distributions of the fuel elements. Earlier calculations have been done on the box-type Mk 2 fuel element. By the results from new flow measurement in the annular-tube-type Mk 4 fuel elements in 1986 a prerequisite was provided for exact temperature calculations.



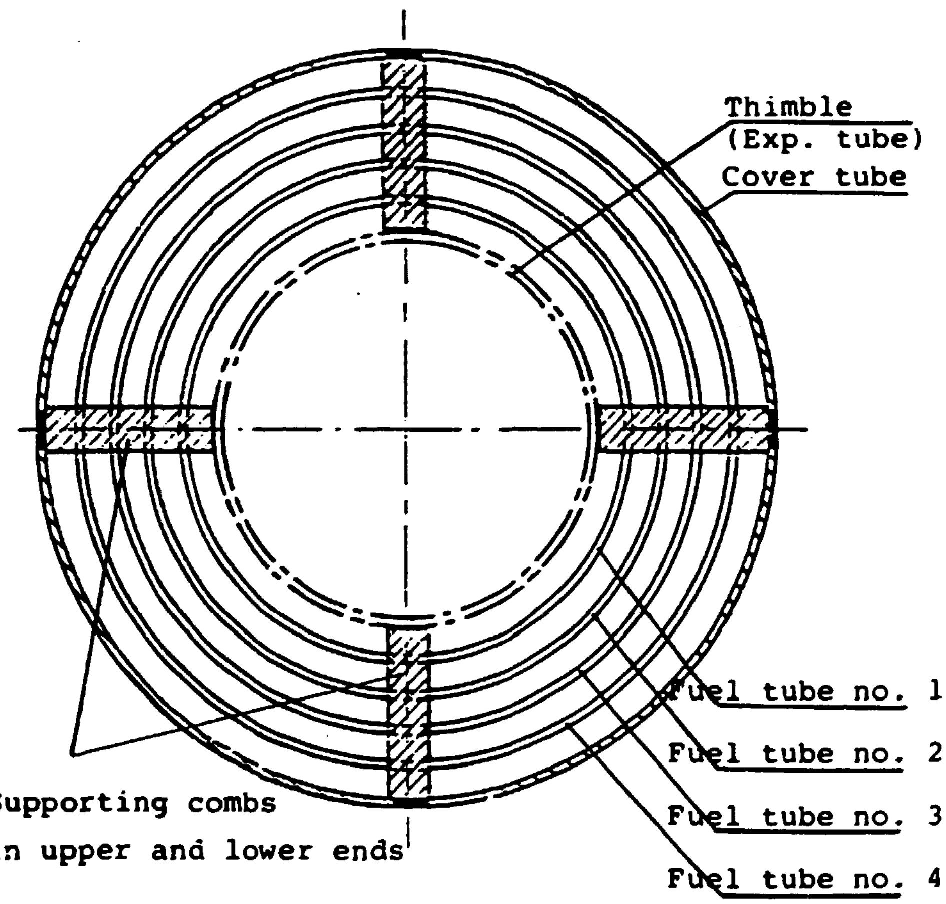


Figure 1. DR 3 fuel element type Mk 4

Each fuel tube consists of 3 plates, welded together longitudinally. The welding seams of neighbour tubes are displaced mutually.

1. Power release and heat deposition in the fuel tubes

The fission power release in the fuel tubes can be calculated by means of the DR 3-SIM code [1)]. The results are given in kW per cm axial length for all four fuel tubes together.

However, a part of this heat release is not absorbed in the fuel tubes. Recent references [8)] divide the release of fission energy from ^{235}U as follows:

Kinetic energy of fission fragments	166,2 MeV
Instantaneous gamma-ray energy	8,0 -
Kinetic energy of fission neutrons	4,8 -
Beta particles from fission products	7,0 -
Gamma-rays from fission products	7,2 -
Neutron reactions in core and coolant	2,3 - *)
Total fission energy	195,5 MeV

*) calculated for the DR 3 core.

The energy from fission fragments and from beta particles will, almost totally, be absorbed in the fuel tubes, but only a fraction ~ 0,2 of the gamma-ray energy and fission neutron energy will be absorbed here. Thus the deposition of energy in the fuel tubes will be:

Kinetic energy of fission fragments	166,2	MeV/fission
Instantaneous gamma-ray energy	0,5	-
Kinetic energy of fission neutrons	0,5	-
Beta particles from fission products	6,1	-
Gamma-rays from fission products	0,5	-
Neutron reactions in core and coolant	2,1	-
	175,9	MeV/fission

The total energy absorption in the fuel tubes is consequently estimated at 175,9 MeV per fission, which means that a fraction of $\mathcal{H} = \frac{175,9}{195,5} = 0,90$ of the total energy released is actually absorbed in the fuel tubes themselves.

2. Flow- and power-distributions between the fuel tubes

The flow distribution between the fuel elements in the core was measured in 1986 [4] in each of the 3 combinations of the main circulators. (2 of the 3 main circulators are operating at a time). See table 6 in appendix 1.

The flow distribution between the 5 cooling channels in a Mk 4 fuel element has been measured in Jülich, GDR. The results have been used by Kaiser [5] for calculation of the flow stability conditions in Mk 4 fuel elements. See table 4 in app. 1.

The power generation distribution between the fuel tubes has been calculated by means of the code DR 3/SIM for Mk 4 fuel elements with 4 fuel tubes as well as 3 fuel tubes, see table 5 in app. 1.

3. Fuel meat-to-coolant heat transfer calculations

The radial heat transfer path is divided . three steps:

- I) - Through the fuel meat
- II) - Through the cladding,
- III) - Through the D_2O boundary layer at the cladding surface.

I). The heat conduction through the heat-generating meat of the fuel tube is calculated by means of the equation [2]:

$$T_o - T_x = \frac{q \cdot \rho_k}{2 \lambda_k} x^2 \qquad (1)$$

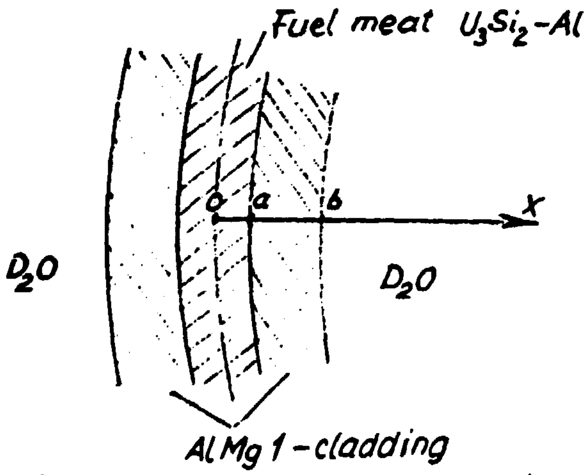


Fig. 2. FUel tube cross section

where T is the temperature (°C)
q is the heat deposition (Wkg^{-1})
ρ_k is the meat density (kgm^{-3})
λ_k is the thermal conductivity ($Wm^{-1}\ {}^oC^{-1}$)

The fuel tubes are considered as plates in these calculations because the tube wall thickness is small compared to the tube diameters.

The power release P_z as calculated by means of the DR 3/SIM code is given in units of $(kW \cdot cm^{-1})$ in 8 intervals of the axial fuel element length.

The relation between q and P_z $(W \cdot m^{-1})$ is

$$q = \frac{\varkappa \cdot \Delta_n \cdot P_z}{2 \cdot a \cdot b_{k,n} \cdot \rho_k} = \frac{\varkappa \cdot \Delta_n \cdot l_k}{A_{k,n} \cdot a \cdot \rho_k} \cdot P_z \tag{2}$$

where Δ_n is the fraction of heat deposition in tube no. n

$b_{k,n}$ (m) is the total of the 3 plate widths of tube no. n

l_k (m) is the axial fuel meat length

$A_{k,n} = 2 \cdot b_{k,n} \cdot l_k$ is the effective heat transfer surface of tube no. n (m^2)

By substitution of q from eq. (2) in eq. (1) we obtain at x=a:

$$T_o - T_a = \frac{\Delta_n \cdot l_k \cdot a \cdot \varkappa}{A_{k,n} \cdot 2 \cdot \lambda_k} P_z \tag{3}$$

II) The temperature drop through the cladding is:

$$T_a - T_b = \frac{\dot{Q}(b-a)}{\lambda_{Al}} = \frac{\Delta_n (b-a) \cdot l_k}{A_{k,n} \cdot \lambda_{Al}} \varkappa P_z \tag{4}$$

where λ_{Al} is the thermal conductivity of aluminium $(Wm^{-1}\,{}^oC^{-1})$

$\dot{Q}$ is the heat flow (Wm^{-2})

and a is the half meat thickness (see fig. 2)

III) The temperature drop through the D_2O film layer close to the cladding surface can be calculated according to 6):

$$T_b - T_{D_2O} = \frac{\dot{Q} \cdot d_h}{\lambda_D \cdot Nu_b} = \frac{\Delta_n \cdot d_h \cdot l_k \cdot \varkappa}{A_{k,n} \cdot \lambda_D \cdot Nu_b} \cdot P_z \tag{5}$$

where d_h is the hydraulic diameter of the cooling channel (m)

$$d_h = \frac{4 \cdot \text{cross section of cooling channel}}{\text{wetted perimeter}}$$

λ_D is the thermal conductivity of D_2O $(Wm^{-1}\,{}^oC^{-1})$

and Nu_b is the Nusselt-number for annular gaps, given by the equation:

$$Nu_b = \frac{0.86\left(\frac{d_i}{d_y}\right)^{0.84} + \left(1-0.14\cdot\left(\frac{d_i}{d_y}\right)^{0.6}\right)}{1+\frac{d_i}{d_y}} \cdot \frac{\frac{\xi}{8}\cdot(Re-1000)\cdot Pr\cdot\left(1+\left(\frac{d_i}{l_k}\right)^{\frac{2}{3}}\right)}{1+12.7\sqrt{\frac{\xi}{8}}\cdot\left(Pr^{\frac{2}{3}}-1\right)}\left(\frac{Pr}{Pr_W}\right)^{0.11} \quad (6)$$

where d_i and d_y are the inner and outer diameter of the cooling channel,

Re is the Reynolds number $Re = \frac{V_z \cdot d_h}{\nu}$ (7)

V_z is the coolant mean velocity (ms^{-1})

ν is the kinematic viscosity of the D_2O film layer (m^2s^{-1})

ξ is the pressure drop coefficient

$$\xi = (1.82 \cdot \log_{10}(Re) - 1.64)^{-2} \quad (8)$$

Pr is the Prandtl number for the D_2O coolant

Pr_W is the Prandtl number for the film layer close to the wall.

4. The D_2O temperature rise by passing through the cooling channels

By means of the methods outlined in section 3 every fuel meat temperature can be calculated assumed the adjacent D_2O coolant temperature is known. The temperature distribution of the D_2O coolant in the cooling channels of a fuel element is given by the equation:

$$\overline{T_{D_2O,z}} - T_i = \int_{-0.3}^{z} \frac{P_z dz}{C_p \cdot F_m} = \frac{1}{C_p \cdot F_m} \int_{-0.3}^{z} P_z dz \quad (9)$$

where P_z (Wm^{-1}) is the axial power deposition in the vertical position z (m) above the core centre plane in the interval dz,

F_m (kgs^{-1}) is the mean coolant mass flow through the element,

and C_p ($Jkg^{-1}K^{-1}$) is the specific heat of D_2O.

This is a mean of all 5 cooling channels. In the cooling channel between tube no. n and tube no. (n-1) the temperature distribution will be:

$$T_{D_2O,z} - T_i = \frac{\Delta_n + \Delta_{n-1}}{2 \cdot C_p \cdot \delta_n \cdot F_m} \int_{-0.3}^{z} P_z dz \qquad (10)$$

where δ_n is the flow ratio in the cooling channel between tube no. n and tube no. (n-1) $(F_n = \delta_n \cdot F_m)$

and Δ_n is the power deposition ratio of tube no. n.

The values of δ_n and Δ_n are given in appendix 1, tables 4 and 5.

5. The total thermo-hydraulic pattern in a fuel element

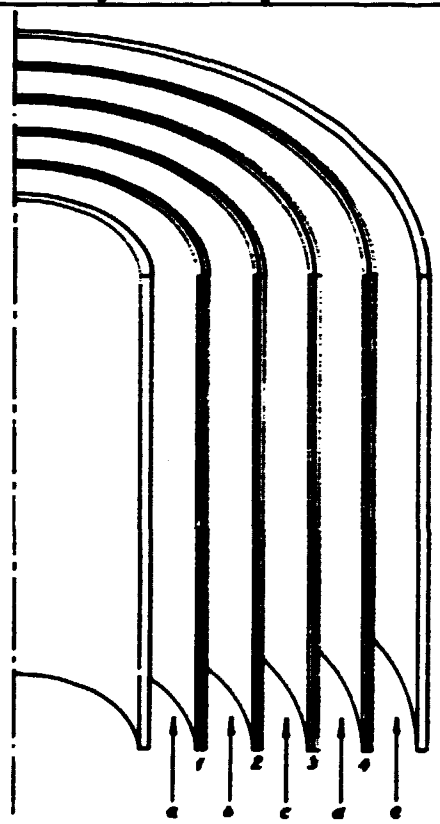


Fig. 3. Fuel tubes and cooling channels in a Mk 4 fuel element with 4 fuel tubes

It is obvious that the temperature rises through the inner and outer channels (a and e) are lowest as these are heated from one side, only. Tube no. 1 and 4 will, consequently, be cooled better and obtain lower temperatures than tube no. 2 and 3. This will cause lower temperatures in the cooling channels b and d, compared with c.

Thus, the heat transport to the inside of each tube is different from that to the outside, so the presumption in chapter 3: That the temperature maximum is situated in the center of the fuel meat (see fig. 2) does not hold.

However, as the temperature drop through the fuel meat itself is very small, a reasonable good approximation is obtained by sticking to the presumption of max. temperature in the meat centre, but assuming different heat transports to the two sides.

Denoting the ratios of heat removal from tube no. n outwards $\beta_{n,o}$ and inwards $\beta_{n,i}$, the heat transport to the cooling channel between tube no. n and tube no. n+1 will be:

$$P_z \cdot \Delta_n \cdot \beta_{n,o} + P_z \cdot \Delta_{(n+1)} \cdot \beta_{n+1,i} \text{ through the area } \tfrac{1}{2} A_{k,n} \tag{11}$$

which will modify eqs. (10), (3), (4) and (5):

$$T_{D_2O,z} - T_i = \frac{\Delta_n \cdot \beta_{n,o} + \Delta_{n+1} \cdot \beta_{n+1,i}}{C_p \; \delta_n \; F_m} \int_{-0.3}^{z} P_z dz \tag{12}$$

$$T_o - T_a = \frac{\Delta_n \cdot l_k \cdot a \cdot \varkappa \cdot \beta}{A_{k,n} \cdot \lambda_k} P_z \tag{13}$$

$$T_a - T_b = \frac{2\Delta_n \cdot (b-a) \cdot l_k \cdot \varkappa \cdot \beta}{A_{k,n} \cdot \lambda_{Al}} P_z \tag{14}$$

$$T_b - T_{D_2O} = \frac{2\Delta_n \cdot d_h \cdot l_k \cdot \varkappa \cdot \beta}{A_{k,n} \cdot \lambda_D \cdot Nu_b} P_z \tag{15}$$

The calculation of the whole temperature distribution in a fuel element is carried out under the assumptions:

a) The β-values are independent of z, i.e. they doesn't vary along the length of the fuel element (this assumption is tested later).

b) The thermal-hydraulic conditions are symmetrical around the vertical axis of the fuel element.

The temperatures can be calculated by iterations:

By choosing a suitable set of the 8 β-values, in such a way that $\beta_{n,i} + \beta_{n,o} = 1$, the temperatures at the core-centre plane (CCP) where $z = 0$ can be estimated by means of equations (12), (13), (14) and (15).

The meat temperature calculated from inside a fuel tube should equal that calculated from outside the tube. If this is not the case, a new set of β-values must be chosen, and the calculation procedure must be repeated until the same meat centre temperature is obtained in each tube by calculations from both sides of the tube.

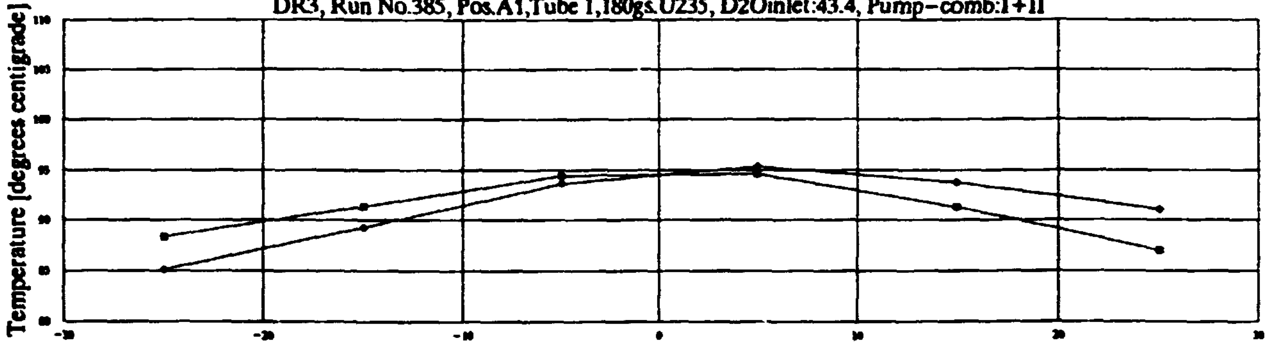
The iterations have been carried out on a computer using the data given in appendix 1. The final set of β-values at CCP were:

Tube no. n	1	2	3	4
$\beta_{n,i}$	0.536	0.517	0.481	0.475
$\beta_{n,o}$	0.464	0.483	0.519	0.525

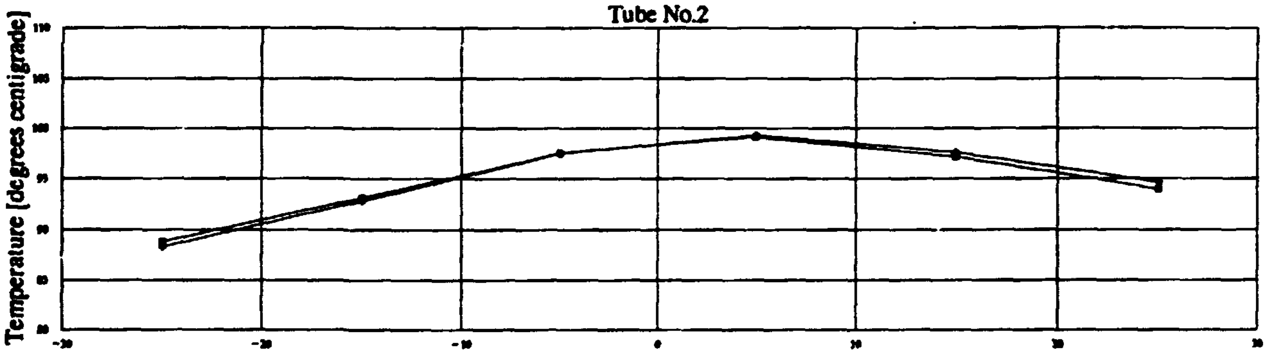
In order to show the significance of the error introduced by the assumption a), the temperature distributions in fuel element C2 in reactor cycle 385 has been calculated from inside as well as from outside of each fuel tube. The results are shown on figure 4. The two curves for each tube coincides

Meat Temperatures in Fuelelement

DR3, Run No.385, Pos.A1,Tube 1,180gs.U235, D2Oinlet:43.4, Pump-comb:I+II



Tube No.2



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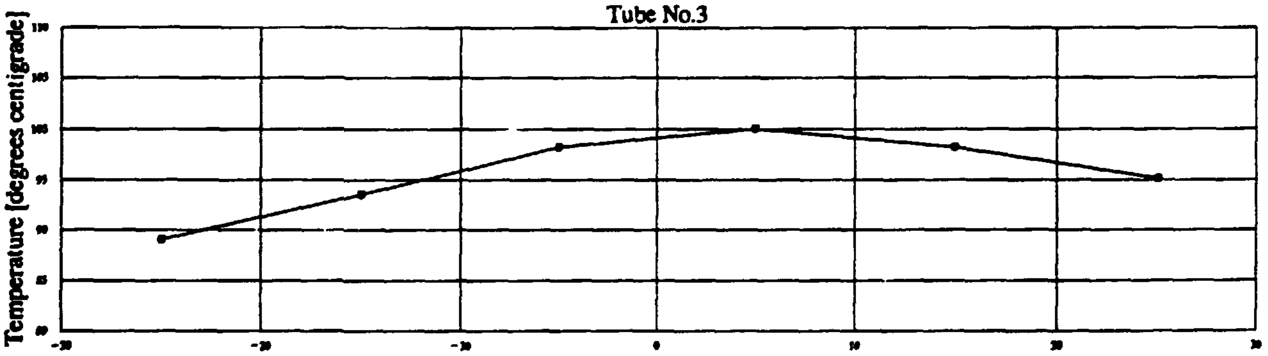
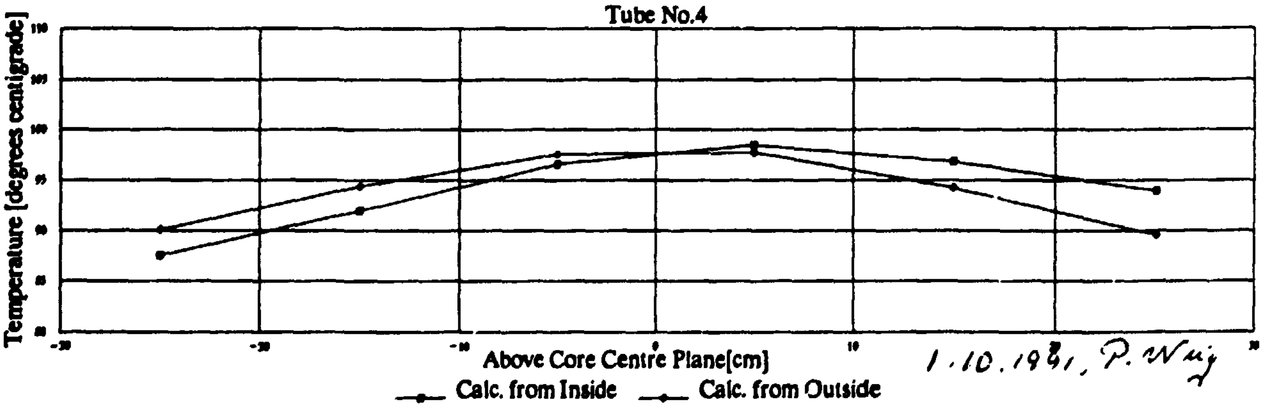


Tube No.4



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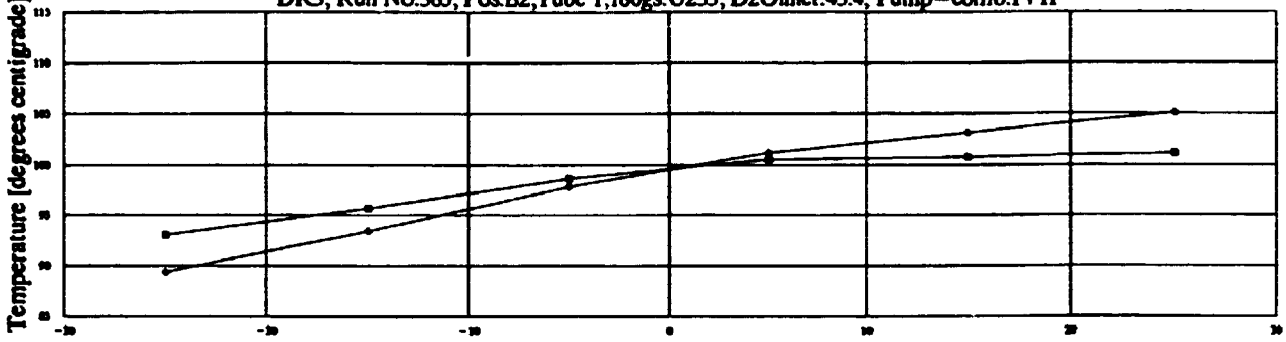
Meat Temperatures in Fuelelement

DR3, Run No.385, Pos.B2,Tube 1,180gs.U235, D2Oinlet:43.4, Pump–comb:I+II



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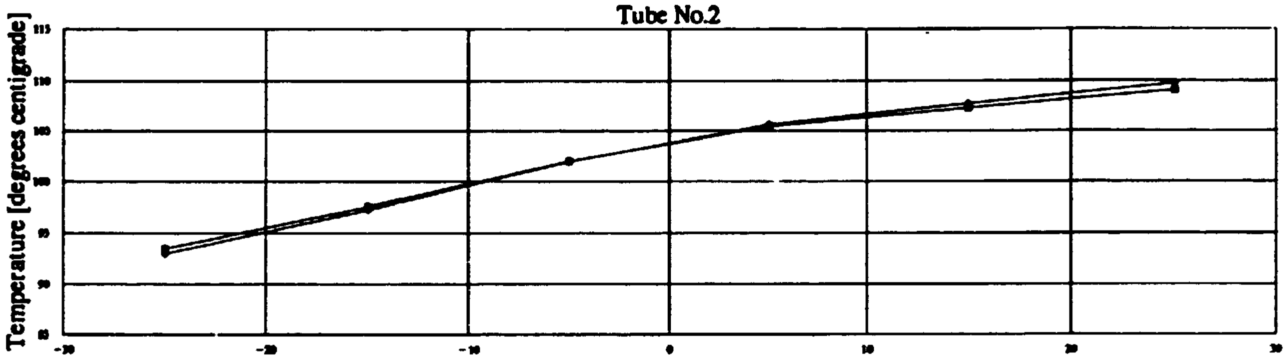

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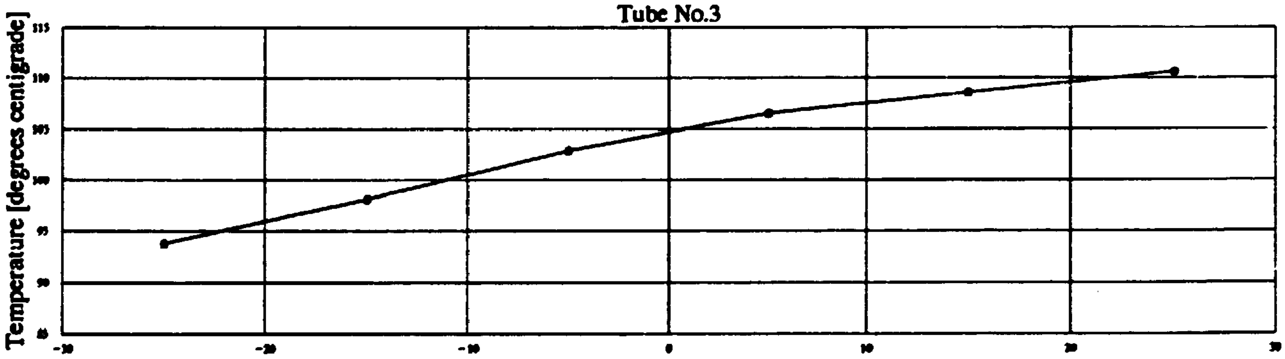
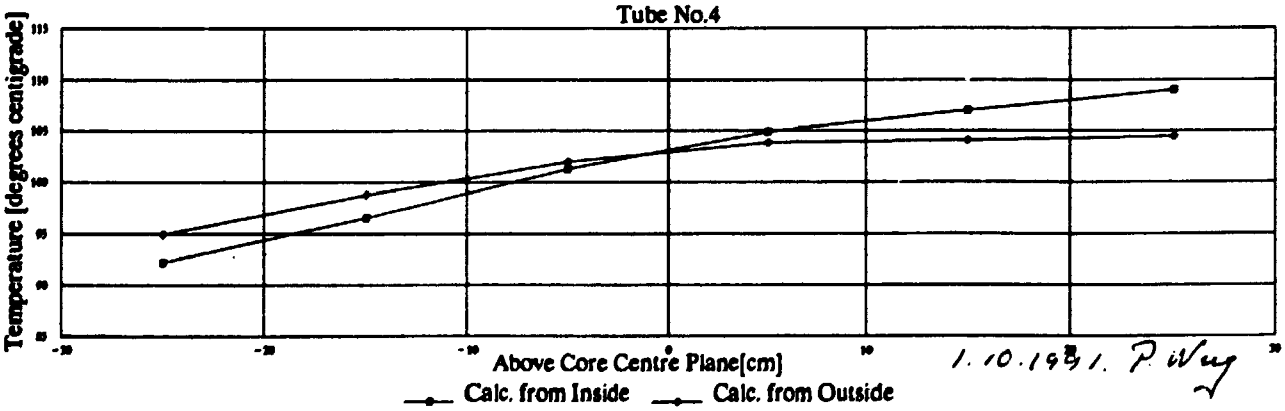


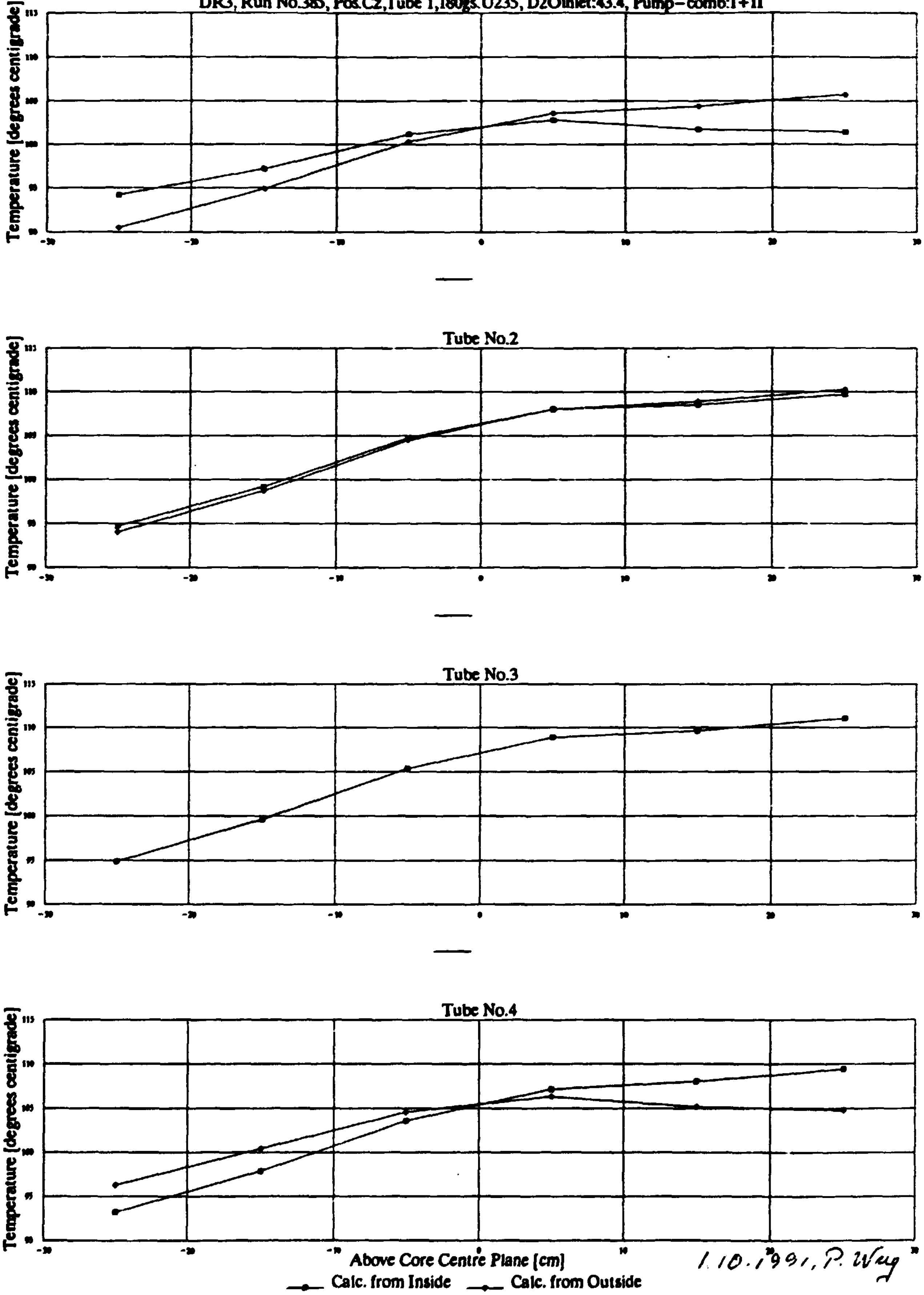
Tube No.4



1. 10. 1991. P. Weg

Meat Temperatures in Fuelelement

DR3, Run No.385, Pos.C2,Tube 1,180gs.U235, D2Oinlet:43.4, Pump-comb:I+II



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at z = 0, which was aimed by the iteration calculation. In the upper and lower ends of the fuel tubes a difference between the outside and inside calculations is noticed, in particular for tubes no. 1 and 4, but the maximum difference is below 2°C. By representing the true meat temperature by the mean from the inside and outside calculations, the error is well below 1°C, which means that the legitimacy of assumption a) seems to be justified.

The last question is: Does the set of β-values in the table above apply to all positions in the core? It is calculated for a LEU 180g fuel element in the core position C2 with a flow 13.20 kg/s and 1000 kW fuel element power. Using the same set of β-values, calculations of meat temperatures from outside and inside of all 4 fuel tubes have been carried out for the same reactor cycle 385 with LEU 180g fuel elements in core position B2 (coolant flow: 13.60 kg/s) and in A1 (flow: 16.20 kg/s), both for 1000 kW fuel element power. The results are shown on figs. 5 and 6. It is seen that the curves crosses close to z = 0 and that the max. difference in the ends is less than 2°C.

All 26 fuel elements flow are between 12.00 and 16.20 kg/s in the 3 combinations of 2 running main circulators 1P1/1,2,3. Only 9 of these 3 x 26 flow values are below that of C2: 13.20 kg/s. As furthermore the β-factors are nearly independent of the element power, it seems to be reasonably justified to use the same set of β-values for all core positions.

As an example, the fuel tube temperature distributions in all 26 core positions have been calculated by means of the method outlined above. The calculations refer to the known conditions of reactor cycle no. 385. The values of ν, ρ_D, c_p, Pr and λ_D refer to the D_2O bulk temperature: 50°C. The value of Pr_W refer to a mean plate temperature of 65°C. The graphs are shown in appendix 2. The maximum meat temperature is 77.1°C in tube no. 3 of the core position D4, which contained a new element generating 530 kW. The reactor power was 10.0 MW.

The pressumed D_2O bulk temperature in the reactor tank was 50°C, which is the normal bulk temperature.

6. Acknowledgements

I wish to thank mr. P. Wiig for doing the computer calculations and preparing the figures, and miss Anni Lambæk for typing the report. The kind assistance of professor J. Bukovsky, M.Sc., Plzen University, CSFR, for revising the report is highly appreciated.

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APPENDIX 1

Heat transmission data

T_{D_2O} (^oC)	ν ($10^{-6}m^2s^{-1}$)	ρ_D *) ($Mg\ m^{-3}$)	λ_D ($10^{-3}Wm^{-1}\,^oC^{-1}$)	Pr	c_p ($Jkg^{-1}K^{-1}$)
50	0,59	1095,7	618	4,46	4220
60	0,50	1090,6	624	3,71	4207
70	0,44	1084,7	629	3,18	4194
80	0,39	1078,2	632	2,76	4181
90	0,34	1071,1	634	2,40	4170
100	0,31	1063,4	636	2,13	4160

Table 1. Heavy water data acc. to [2)]

Channel between tube no.	a (0-1)	b (1-2)	c (2-3)	d (3-4)	e (4-5)
d_i ($10^{-3}m$)	54.05	63.85	73.65	83.45	93.25
d_y ($10^{-3}m$)	60.85	70.65	80.45	90.25	100.05
$\frac{d_i}{d_y}$	0.8883	0.9038	0.9155	0.9247	0.9320
d_h ($10^{-3}m$)	6.80	6.80	6.80	6.80	6.75
V_z (ms^{-1})	3.10	2.95	2.71	2.91	2.79
l_k (m)	0.600	0.600	0.600	0.600	0.600

Table 2. Cooling channel data

	Meat	Cladding
ρ (Mgm^{-3})	12.20	2.70
λ ($Wm^{-1}\ {}^{o}C^{-1}$)	120	221

Table 3. Meat and cladding data

Cooling channel between tubes no.s	a (0-1)	b (1-2)	c (2-3)	d (3-4)	e (4-5)
Flow ratio δ_n	0.162	0.178	0.189	0.229	0.242

Table 4. Flow distribution ratios δ_n in a Mk 4 fuel element

Tube no.	1	2	3	4
Power deposition ratio Δ_n in a				
3-tube fuel elem.	0	0.288	0.328	0.384
4-tube fuel elem.	0.197	0.226	0.264	0.313

Table 5. Power deposition ratios Δ_n in a Mk 4 LEU fuel element

Table 6a, 6b and 6c

Flowmeasurements in the DR 3 core June 12th and 13th 1986

The measurements were carried out at a D_2O-temperature of 50^oC, which is the normal operating temperature at 10 MW. The accuracy is estimated to be $\pm$ 5%. Values in the matrixes are in kg/s.

Pump combination 1P1-1 + 1P1-2: 360 kg/s

	A1: 16.2	A2: 16.0	A3: 13.8	A4: 13.2	
B1: 12.8	B2: 13.6	B3: 13.2	B4: 13.5	B5: 13.4	B6: 13.3
C1: 12.2	C2: 13.2	C3: 13.0	C4: 15.0	C5: 15.5	C6: 13.2
D1: 13.0	D2: 13.6	D3: 13.4	D4: 13.8	D5: 13.8	D6: 13.7
	E1: 15.2	E2: 15.2	E3: 13.8	E4: 13.2	Table 6a

Pump combination 1P1-2 + 1P1-3: 360.5 kg/s

	A1: 15.5	A2: 15.5	A3: 13.9	A4: 12.8	
B1: 12.5	B2: 13.7	B3: 13.2	B4: 13.5	B5: 13.7	B6: 13.6
C1: 12.0	C2: 13.3	C3: 13.2	C4: 15.1	C5: 15.5	C6: 13.3
D1: 13.0	D2: 13.7	D3: 13.7	D4: 14.0	D5: 13.8	D6: 13.2
	E1: 15.8	E2: 15.6	E3: 13.8	E4: 13.7	Table 6b

Pump combination 1P1-1 + 1P1-3: 365 kg/s

	A1: 16.2	A2: 16.0	A3: 13.9	A4: 13.5	
B1: 12.5	B2: 13.7	B3: 13.6	B4: 13.9	B5: 13.9	B6: 12.2
C1: 13.3	C2: 13.5	C3: 13.6	C4: 15.0	C5: 15.5	C6: 13.7
D1: 13.1	D2: 13.7	D3: 13.8	D4: 14.1	D5: 14.0	D6: 13.3
	E1: 15.9	E2: 15.6	E3: 13.9	E4: 13.9	Table 6c

The dotted ellipses represent the positions of the upcomers (elliptical because of the compressed delineation of the core).

Table 7a, 7b and 7c

DATA FOR LEU-FUEL ELEMENTS

Type: Mk 4 acc. to Risø drawing no. 73.33 (15. Jan. 76).

Enrichment: 19.75% ^{235}U, balance ^{238}U (+ impurities <2.0%).

Cladding: AlMg1 (98% Al, 1% Mg, balance Si, Fe, Cu, Mn, Cr, Zn, Ti).

Dimensions of plates:

Table 7a

	Thickness mm	Length mm	Width mm
Wide plates, meat	0.531	580.0	90.0
Narrow plates, meat	0.531	580.0	60.0
Cladding plates	0.464	-	-
Finished plate, wide	1.46	640.9	102.0
- - , narrow	1.46	640.9	69.0

			Weight of 60 cm length:
Cover tube:	Outside diameter:	103.00 mm	774.86 g
	Tube thickness:	1.50 mm	
Thimble:	Outside diameter:	54.05 mm	448.38 g
	Tube thickness:	1.63 mm	

U-density in meat: 3.29 g/cm^3

^{235}U-density in meat: 1.66 x 10^{21} at/cm^3

U_3Si_2-powder composition: <20% fine (< 45 μm)

Density, U_3Si_2: 12.2 g/cm^3

- , meat: 5.4 g/cm^3

Heat conductivity, meat 98 W/m^oC at 60^oC

Density, cladding: 2.70 g/cm^3

Heat conductivity, cladding: 221 W/m^oC at 60^oC

Table 7b

Procentage content in → of ↓	Meat		1 cm tube in the fuel zone	
	Weight %	Vol. %	Weight %	Vol. %
U	61.4		29.5	
U_3Si_2	66.0	29.0	31.7	9.2
Al	34.0	67.5	68.3	89.7
Porosity	-	3.5	-	1.1

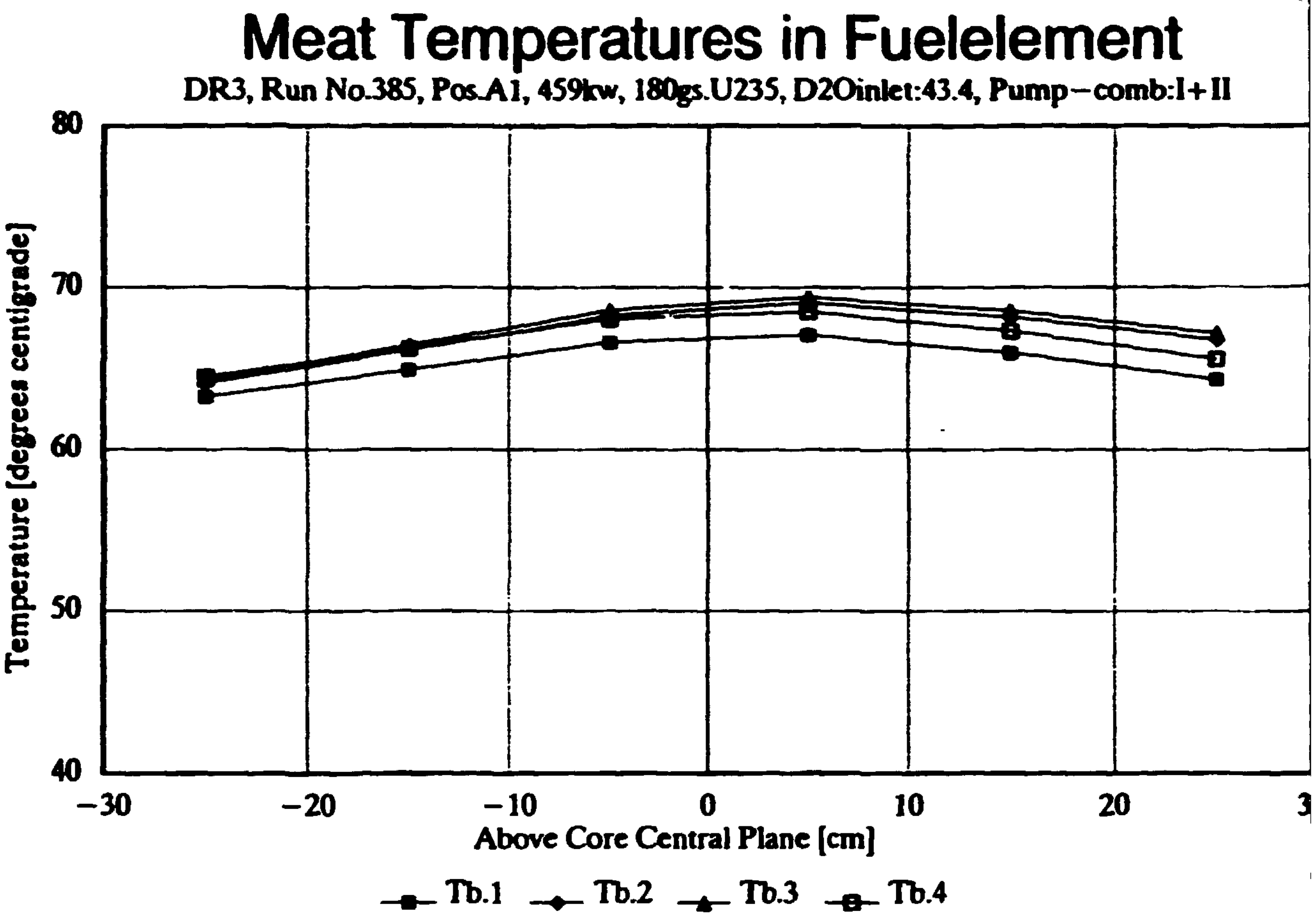
Table 7c

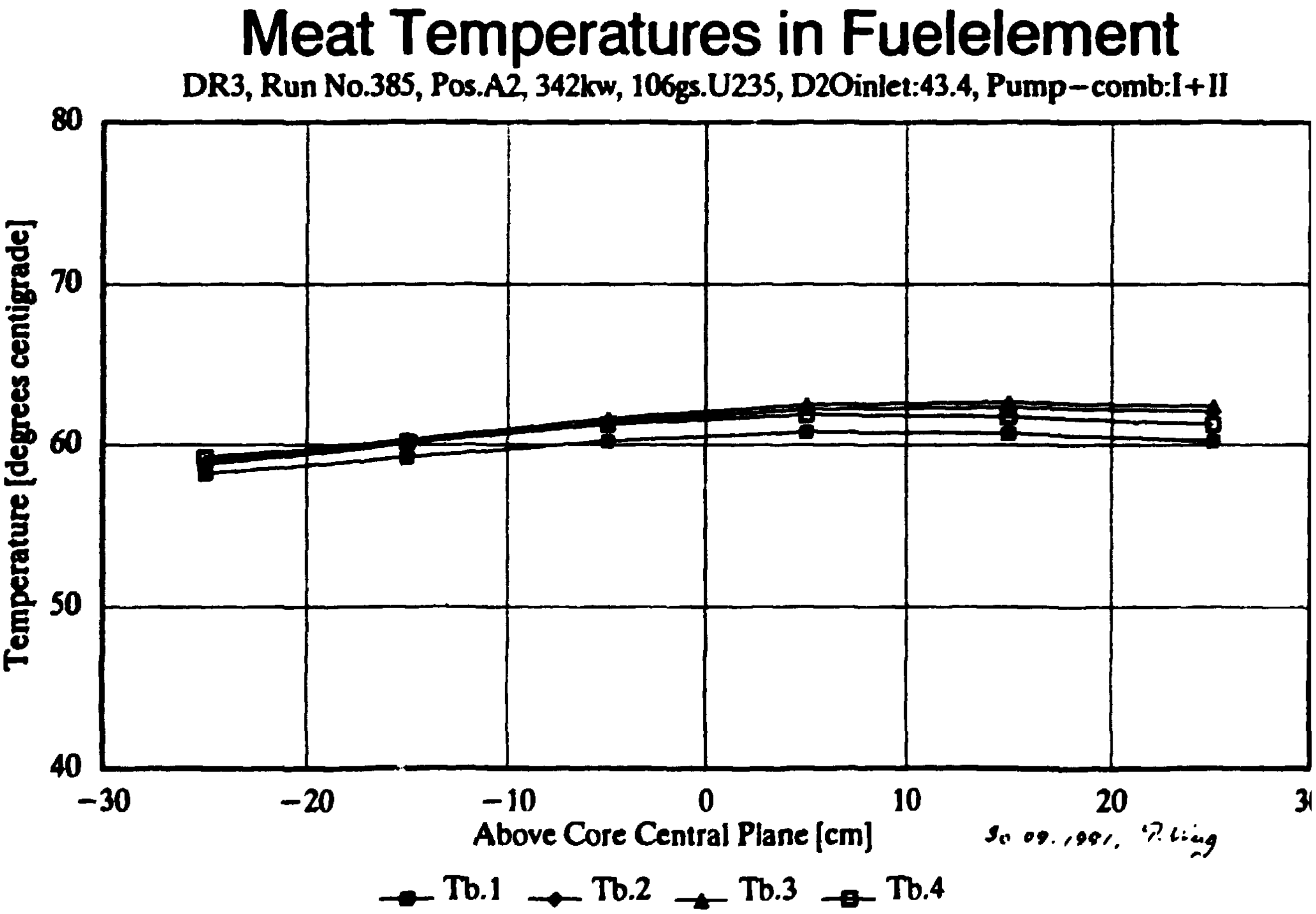
Tube no.	1	2	3	4	Total
MEASURES (mm)					
Length, tube	660.4	660.4	660.4	660.4	
- , meat	600	600	600	600	
Thickness, tube	1,50	1.50	1.50	1.50	
- , meat	0.546	0.546	0.546	0.546	
- ,cladd.	0.477	0.477	0.477	0.477	
Tube diam., outer	63.85	73.65	83.45	93.25	
Angle of covering, meat	311.0°	313.5°	315.5°	317.0°	
VOLUMES (cm^3)					
U_3Si_2	16.12	18.81	21.50	24.19	80.62
Al in meat	37.37	43.60	49.82	56.05	186.83
Porosity	1.94	2.26	2.59	2.91	9.70
Total, meat	55.43	64.67	73.90	83.14	277.14
Al-cladding	138.61	159.87	181.13	202.39	682.00
Total, tube	194.04	224.54	255.03	285.53	959.14
WEIGHTS (g)					
^{235}U	36.0	42.0	48.0	54.0	180.0
U	182.3	212.7	243.0	273.4	911.4
Si	14.3	16.7	19.1	21.5	71.6
U_3Si_2	196.6	229.4	262.1	294.9	983.0
Al in meat	100.9	117.7	134.5	151.5	504.6
Total, meat	297.5	347.1	396.6	446.5	1487.7
Al-cladding	374.2	431.6	489.0	546.4	1841.2
Total, tube	671.8	778.8	885.7	992.9	3329.20
	Inclusi	ve cover	tube and	thimble:	4552.44
SURFACE AREAS(cm^2)					
Tube surface	2587	2994	3400	3807	12789
- - off meat	2031	2369	2708	3046	10153

COOLING CHANNEL WIDTH (mm)

Channel	Thimble-1	1-2	2-3	3-4	4-cover tube
Width	3.40	3.40	3.40	3.40	3.375

APPENDIX 2





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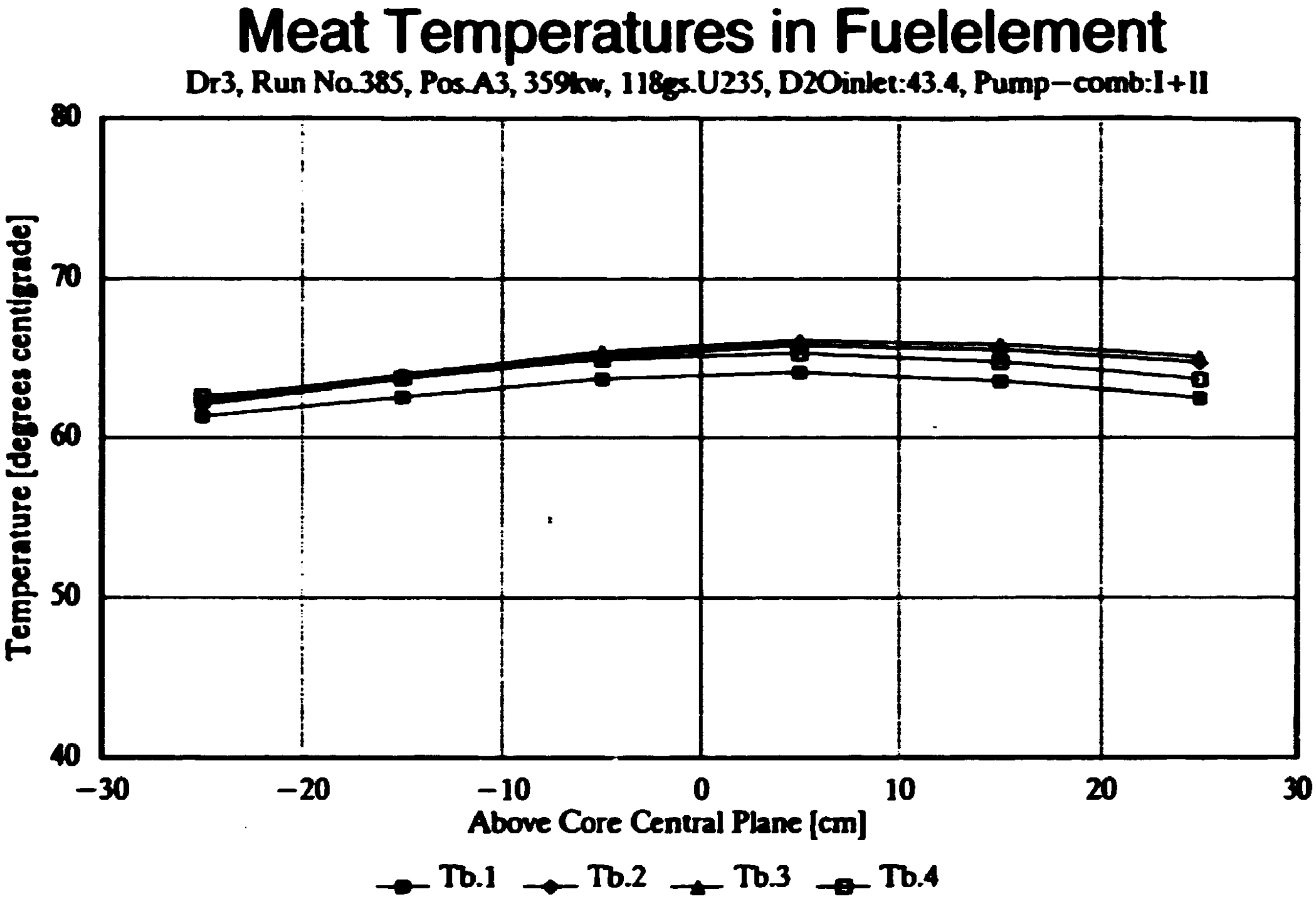
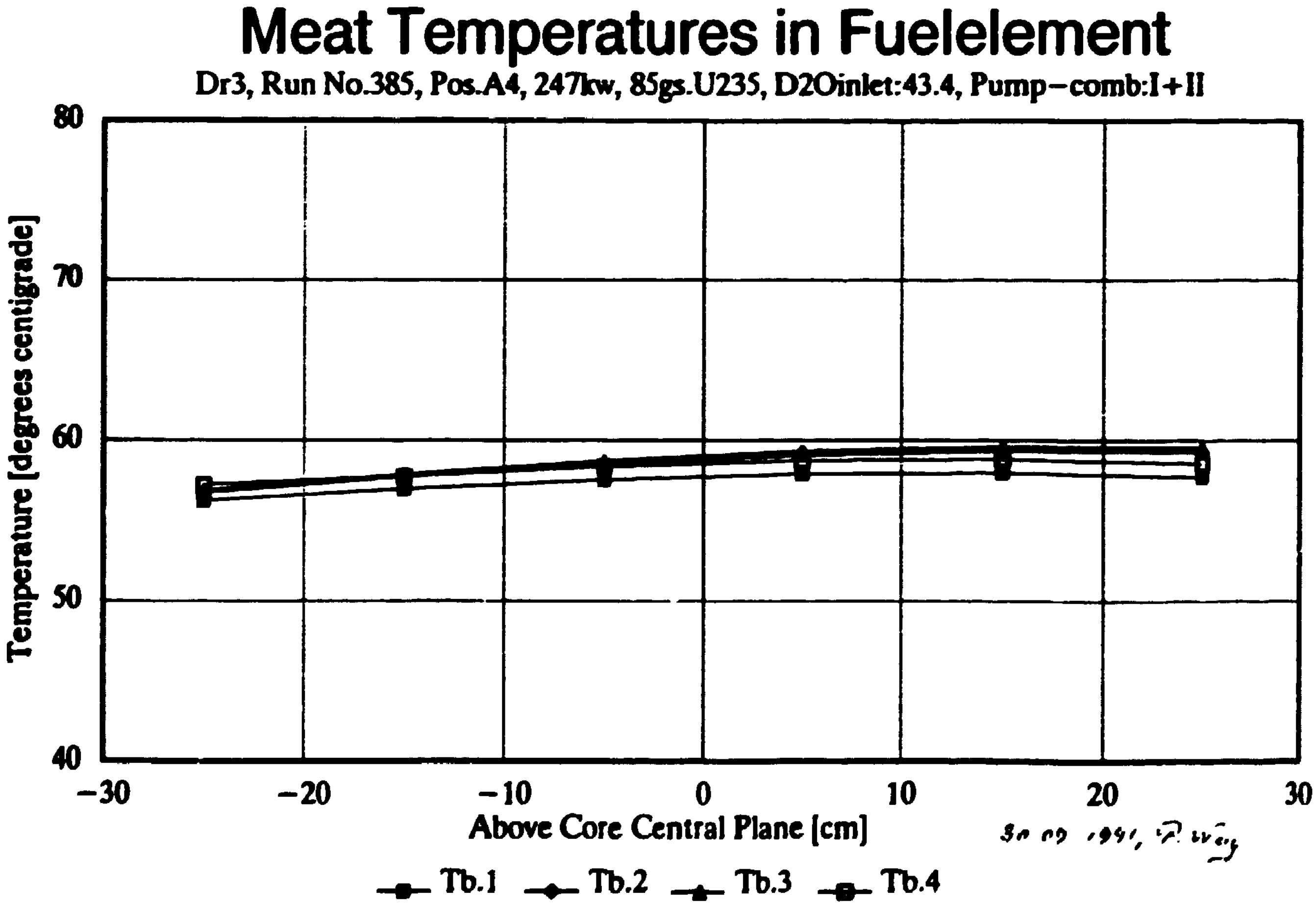
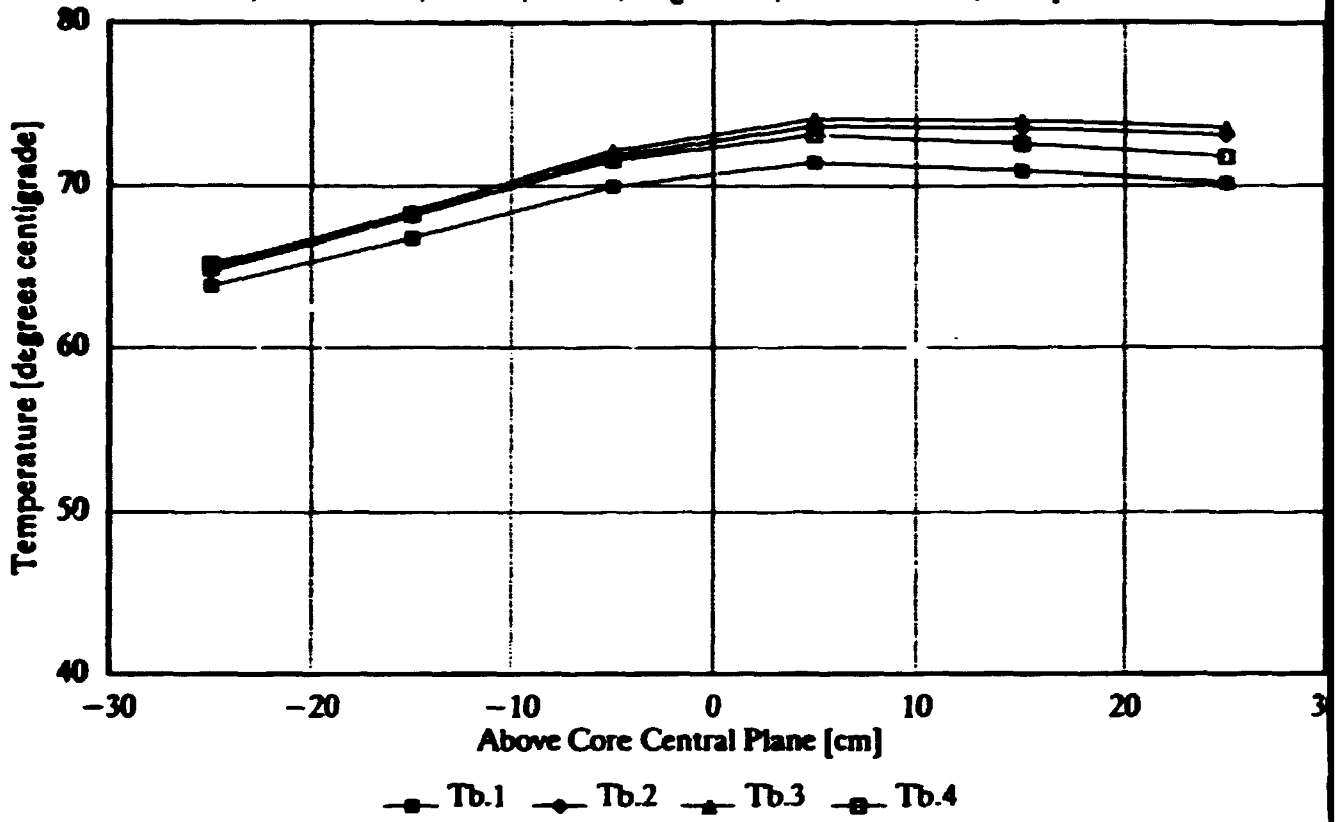




30.09.1991, R. Weiß

Meat Temperatures in Fuelelement

Dr3, Run No.385, Pos.B1, 441kw,180gs.U235, D2Oinlet:43.4, Pump-comb:I+II



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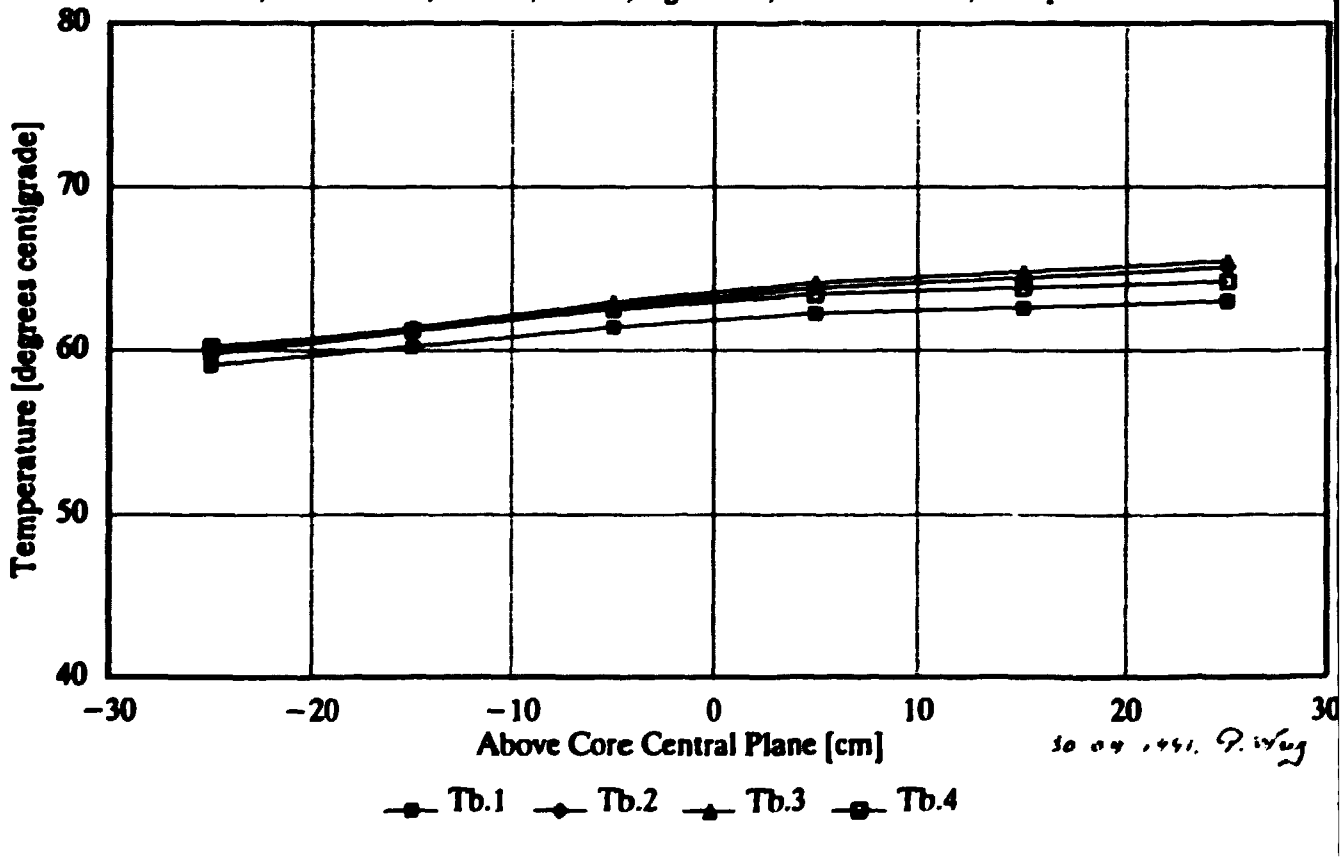

30.04.1991. P. Weg

Meat Temperatures in Fuelelement

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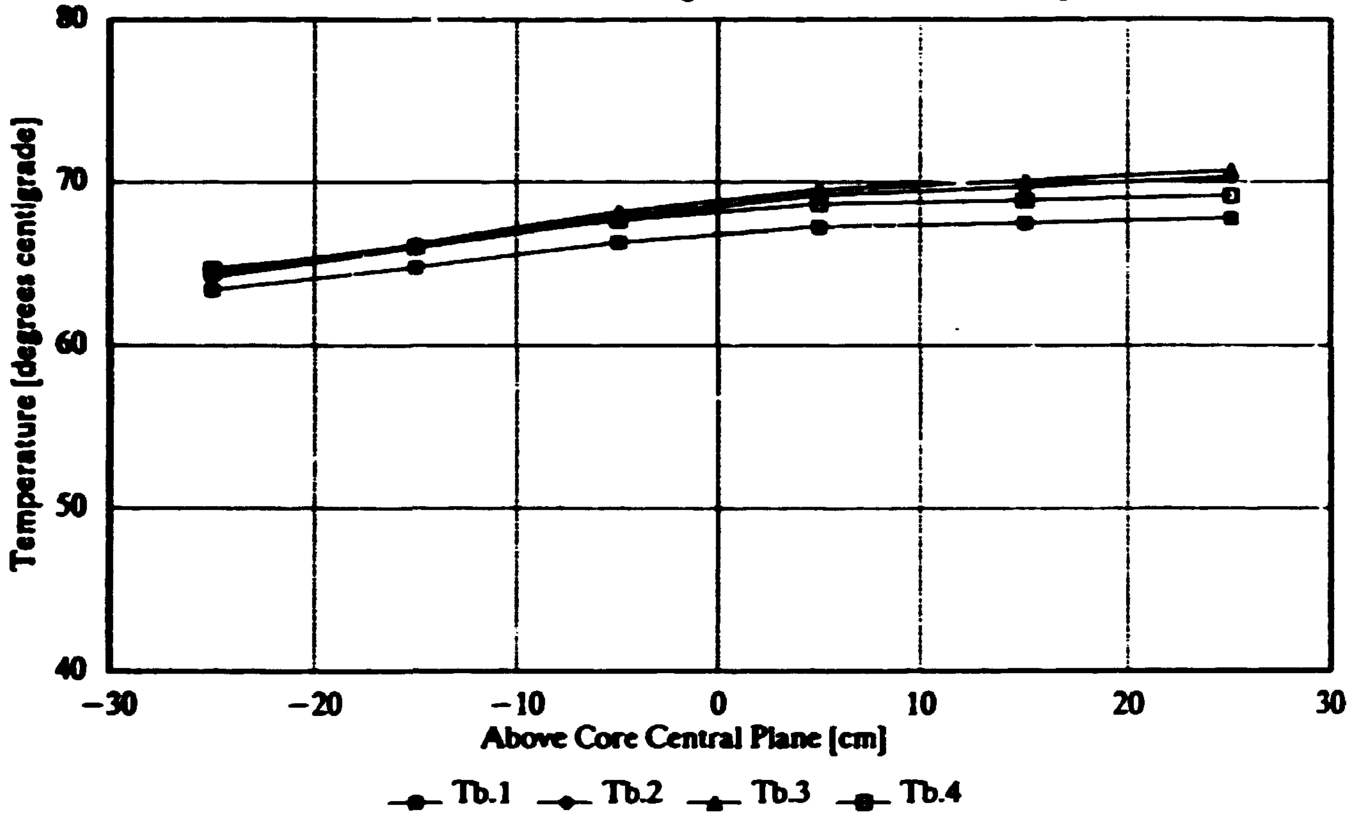

Meat Temperatures in Fuelelement

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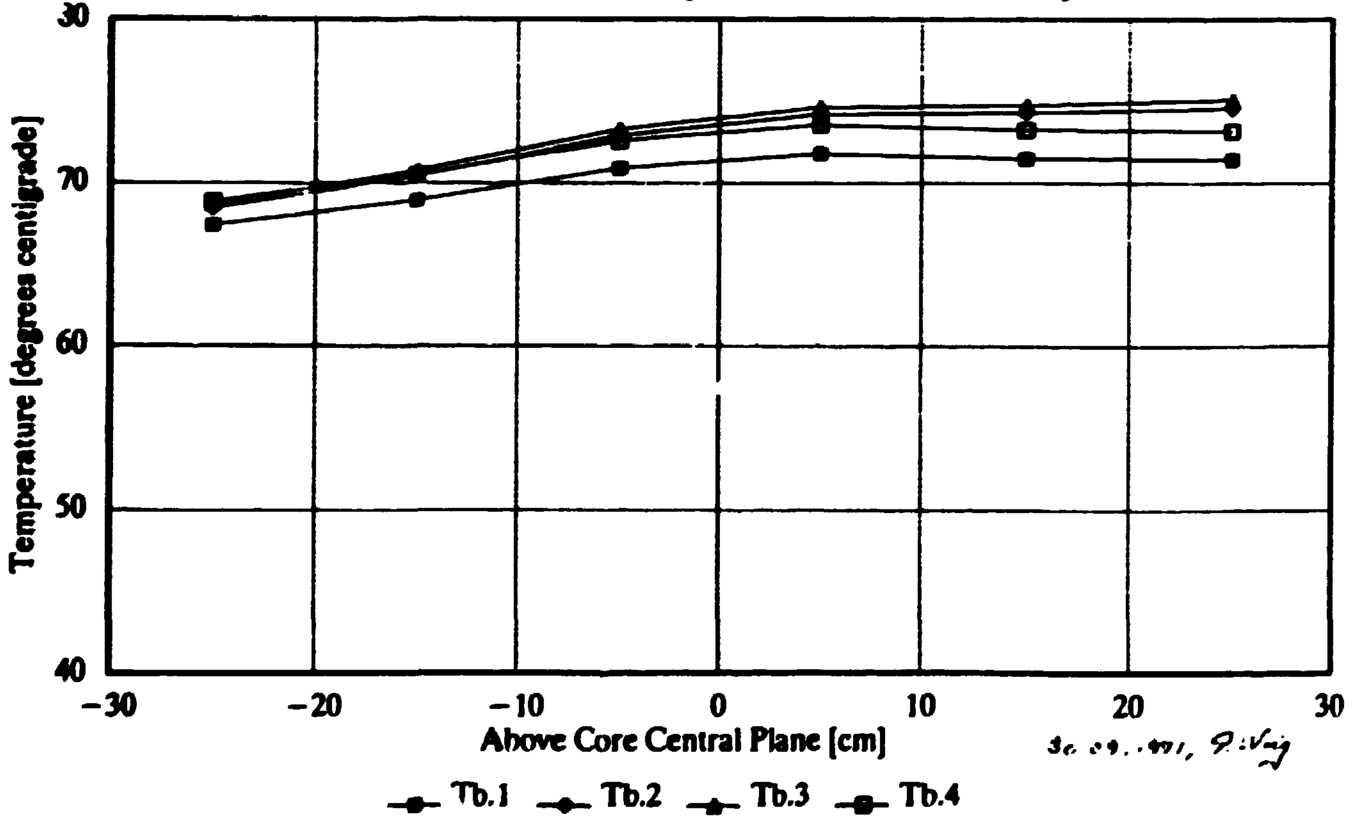

A2/5

Meat Temperatures in Fuelelement

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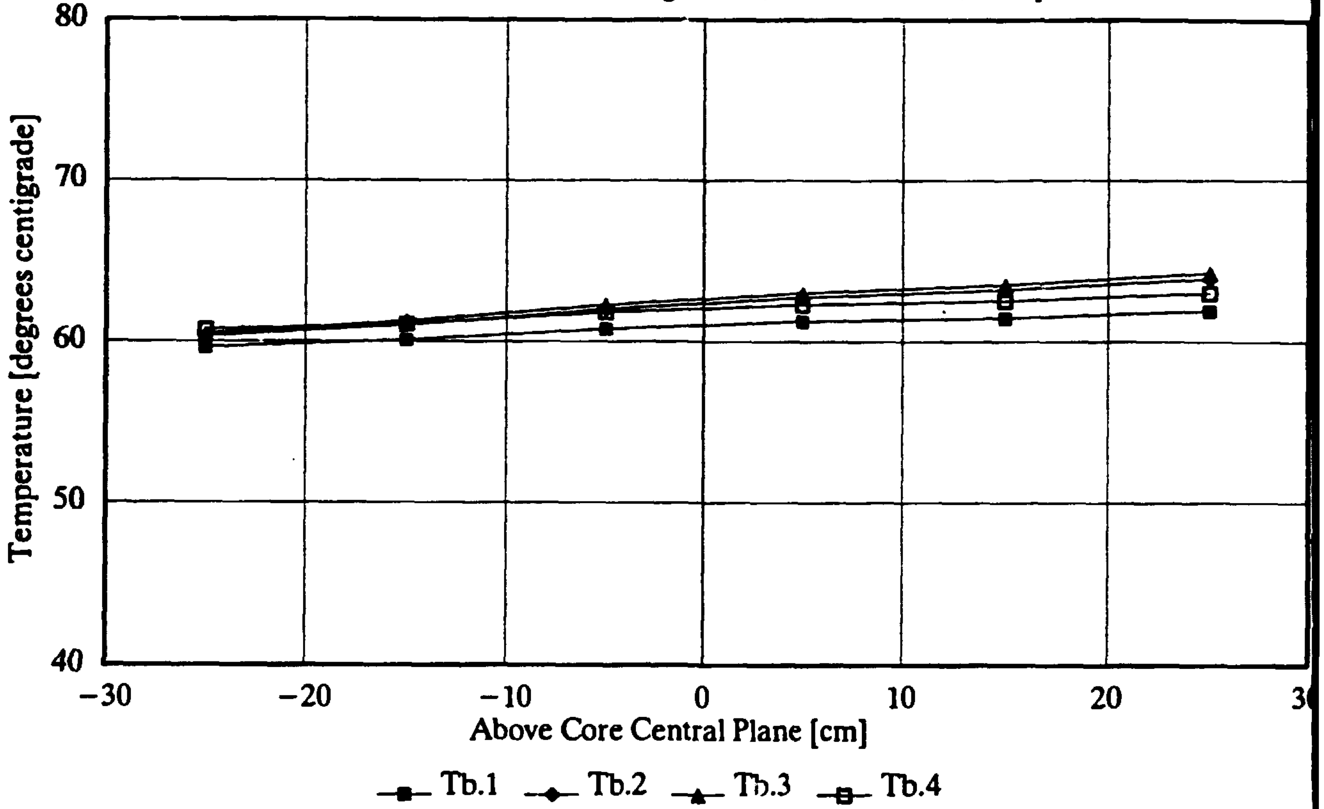

Meat Temperatures in Fuelelement

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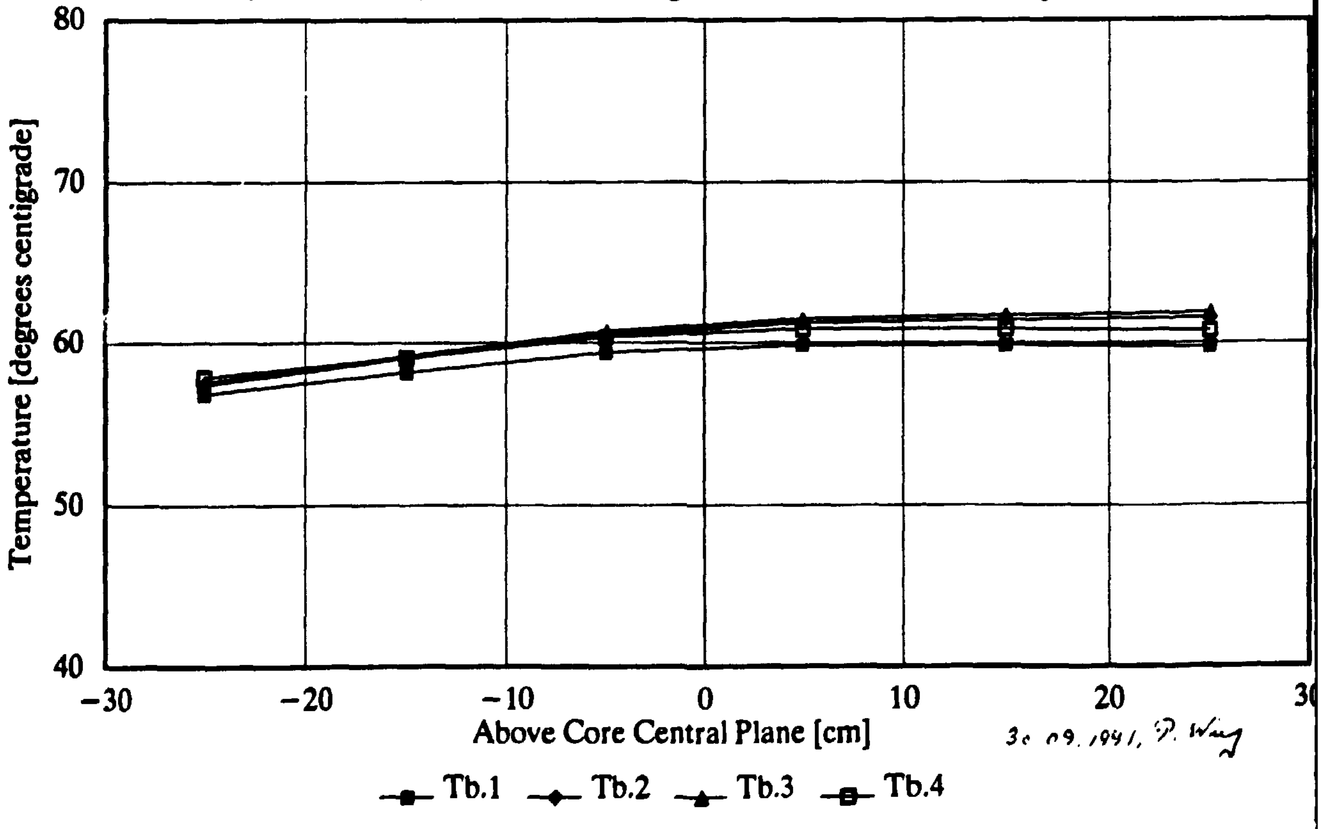
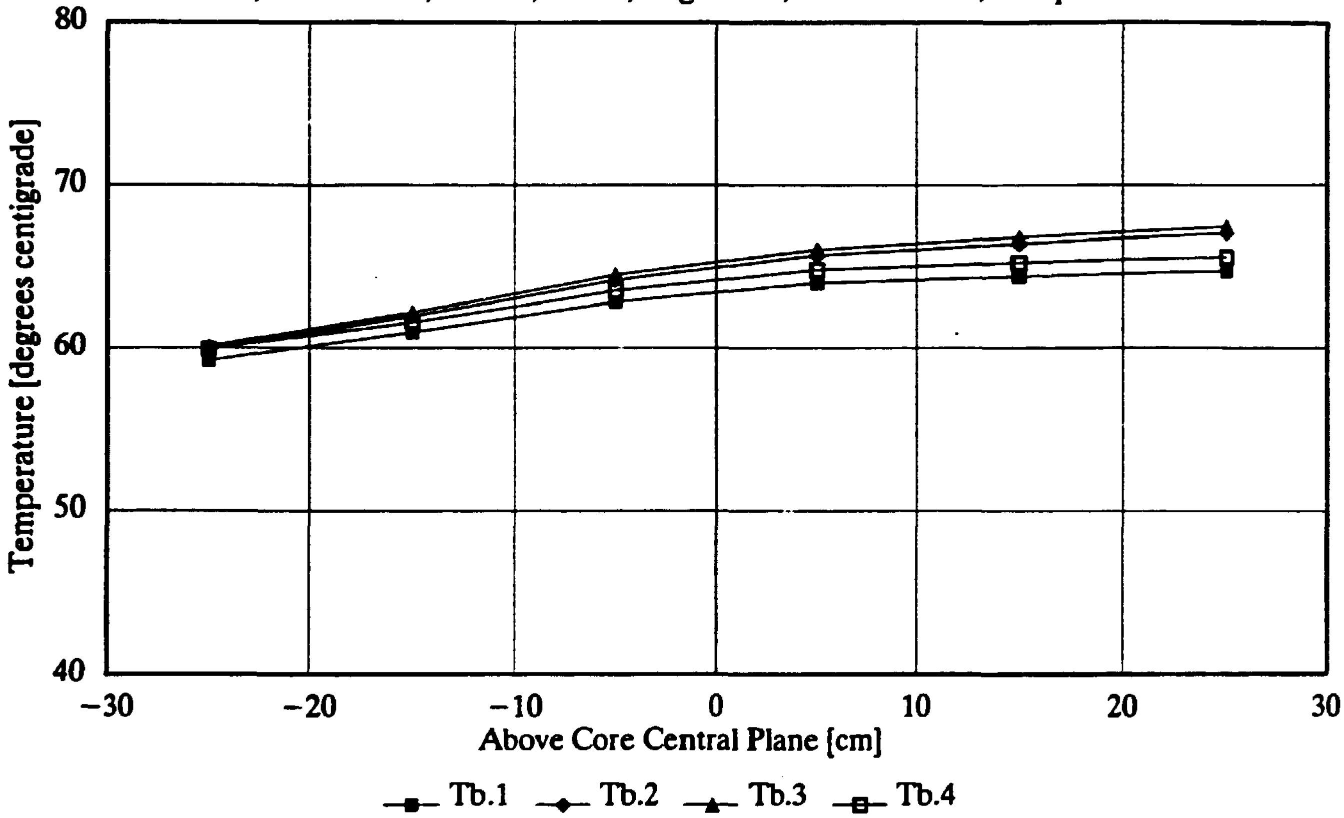


30.09.1991, P. Wing

Meat Temperatures in Fuelelement

DR3, Run No.385, Pos.C1, 321kw,110gs.U235, D2Oinlet:43.4, Pump−comb:I+II



Meat Temperatures in Fuelelement

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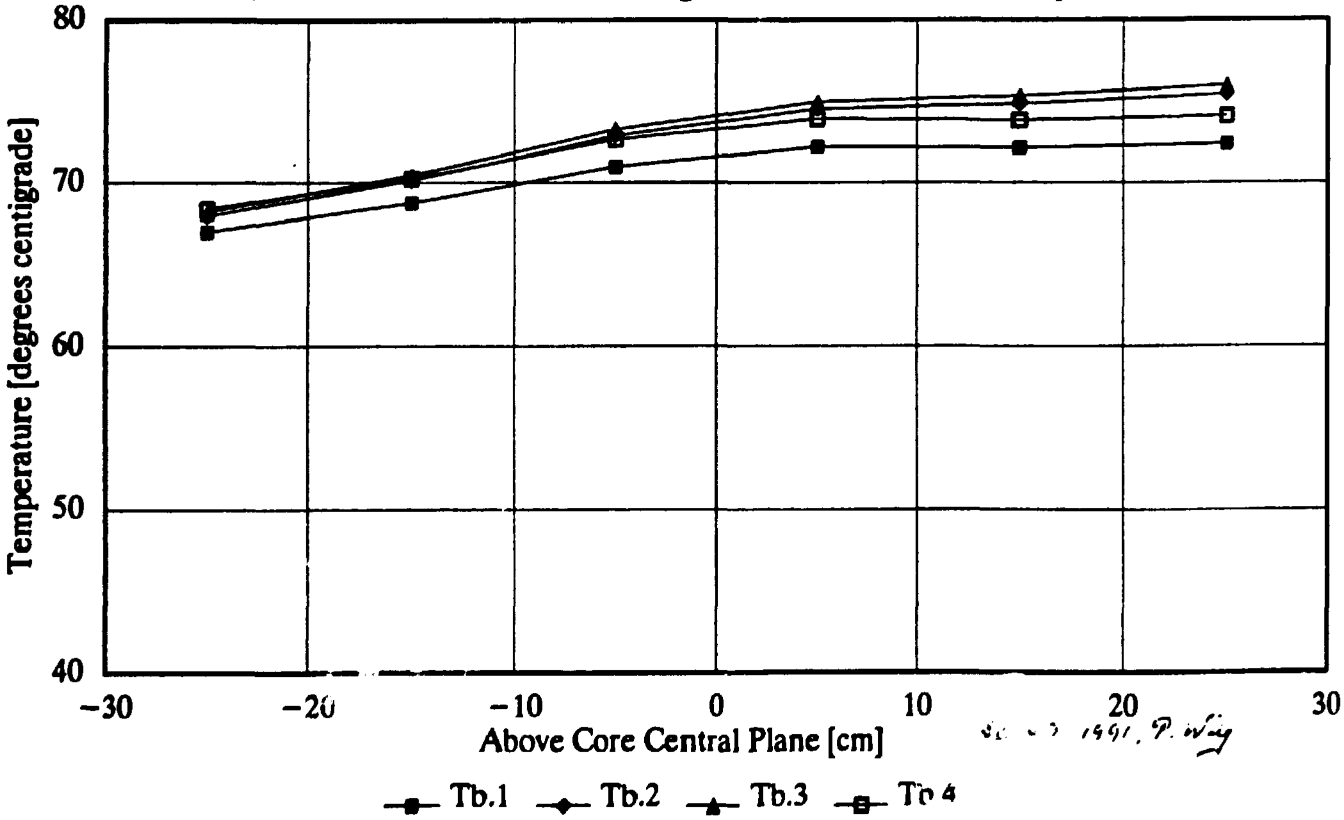
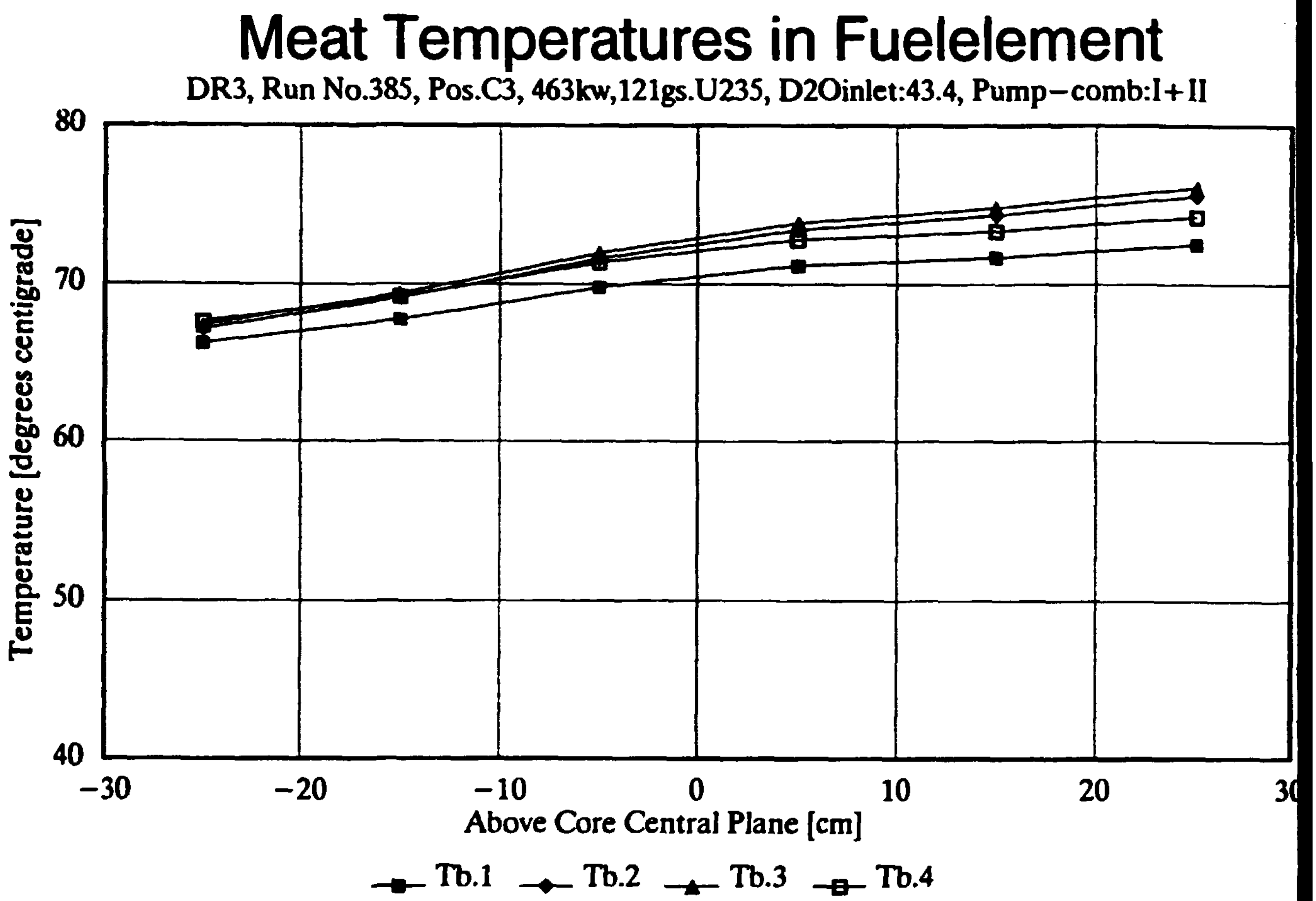
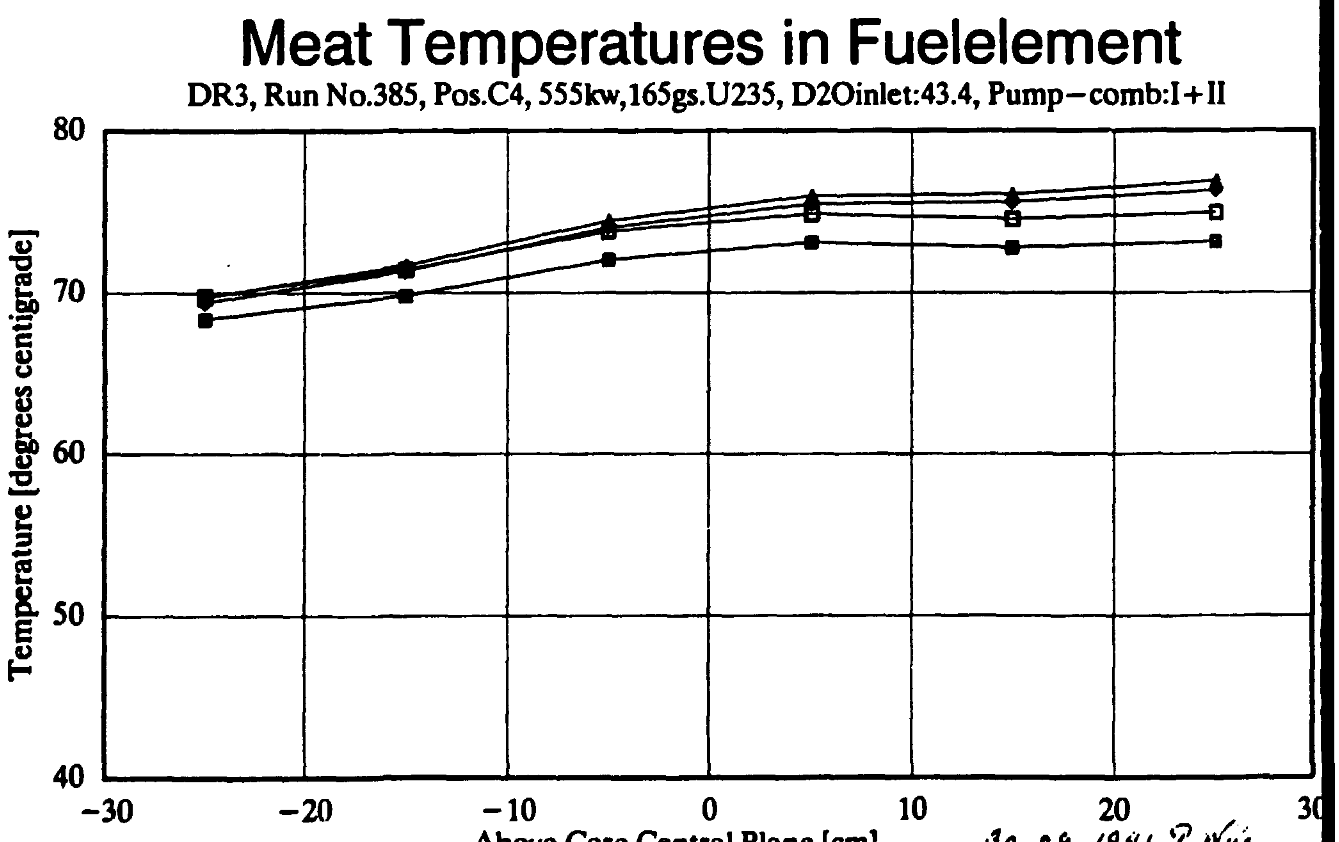
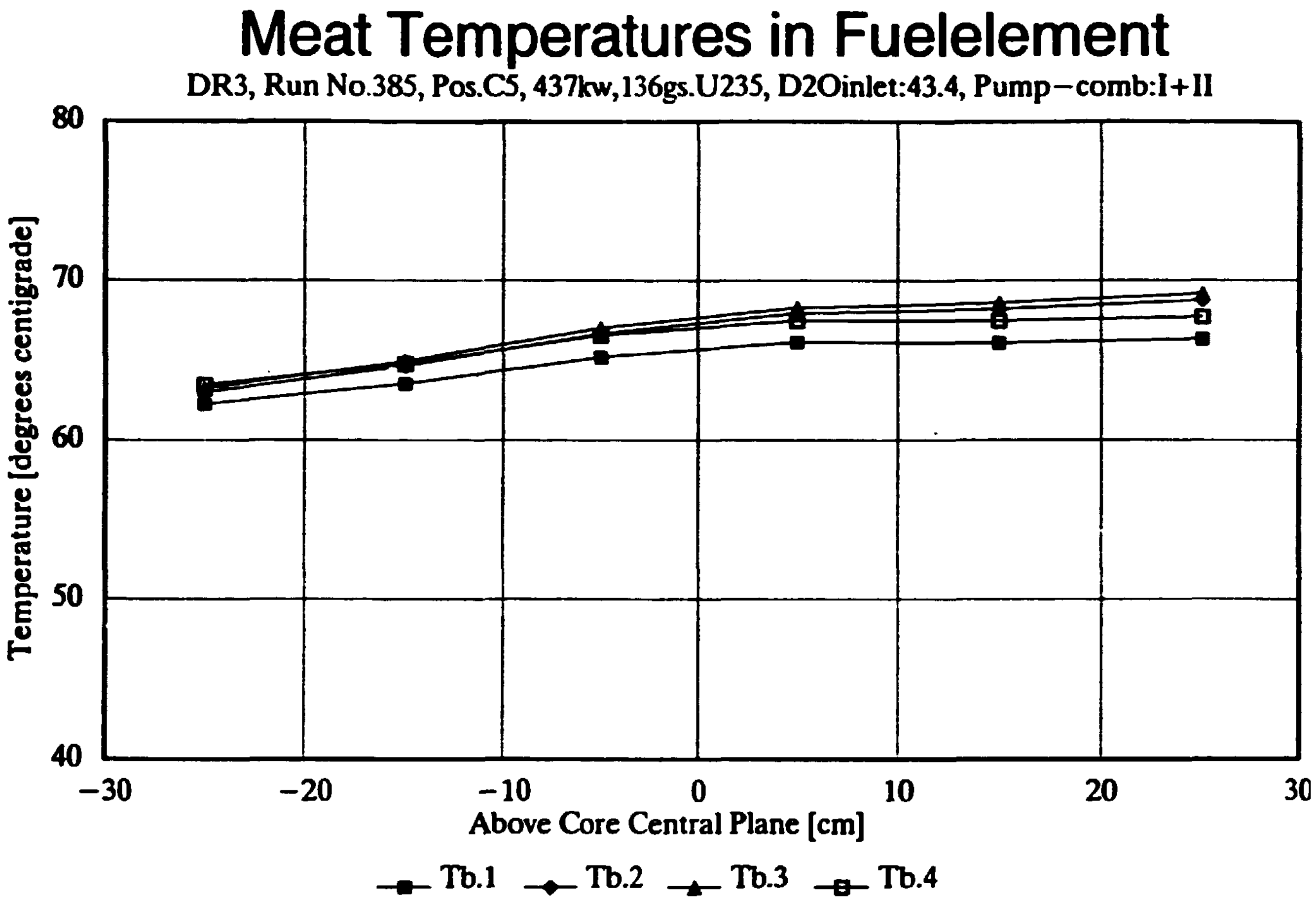
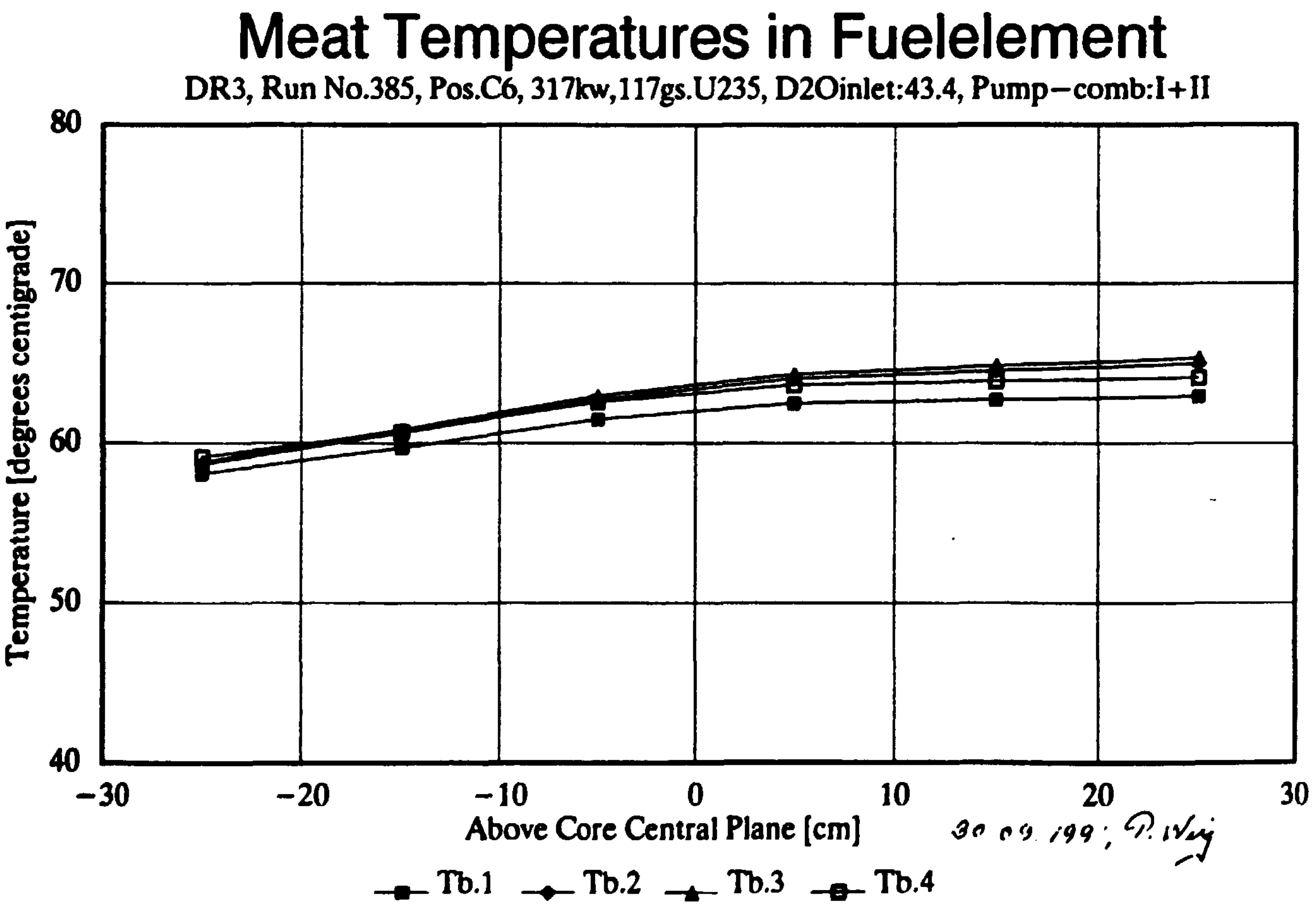






30.09.1991. P. Nij

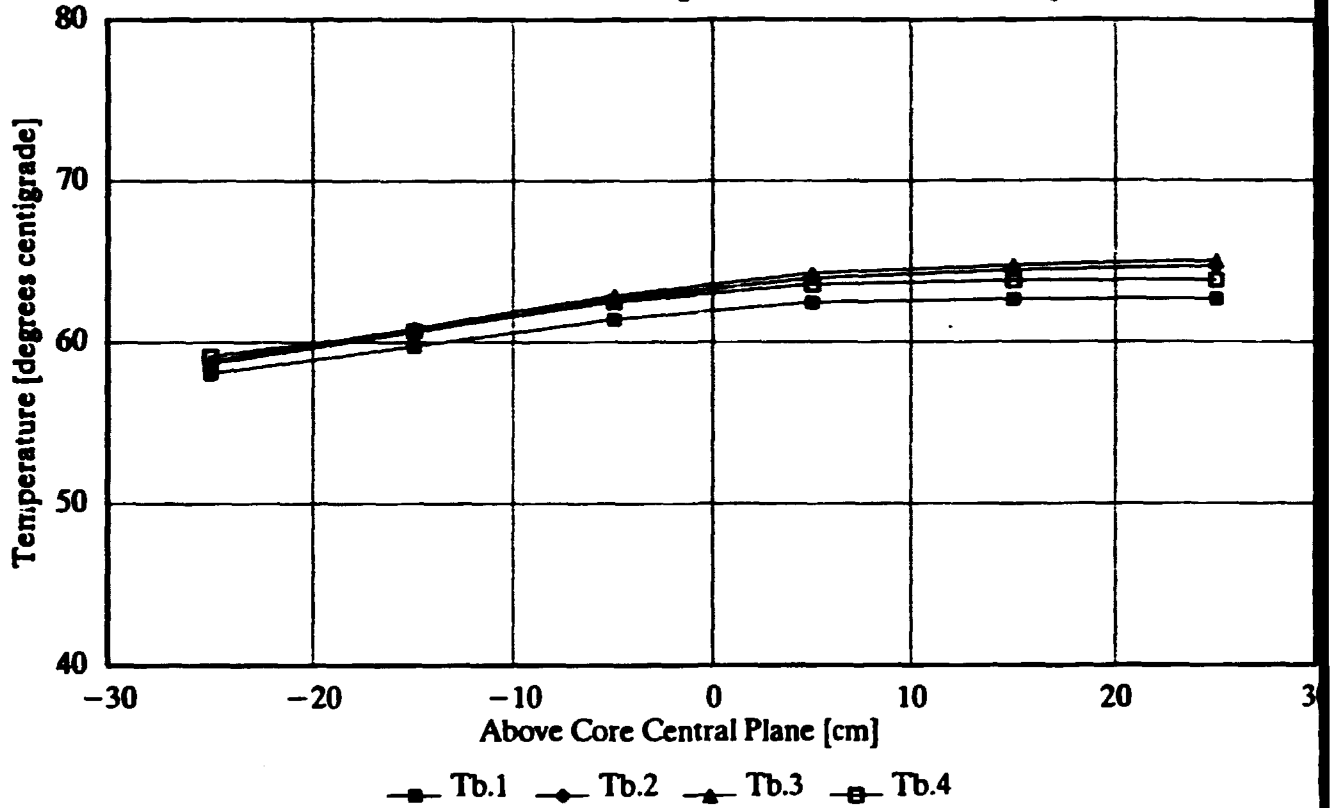




30.09.199; P. Wiij

Meat Temperatures in Fuelelement

DR3, Run No.385, Pos.D1, 312kw,112gs.U235, D2Oinlet:43.4, Pump–comb:I+II



Meat Temperatures in Fuelelement

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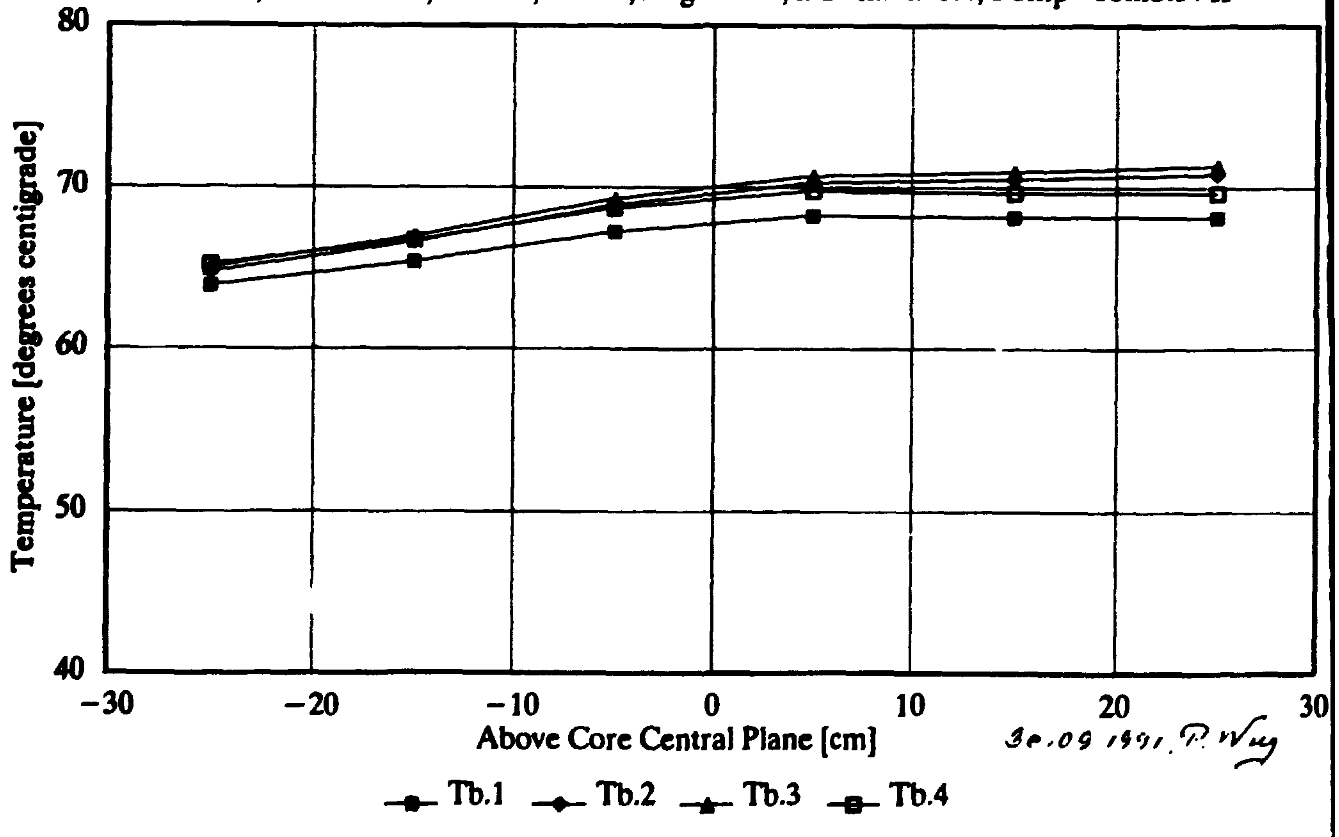
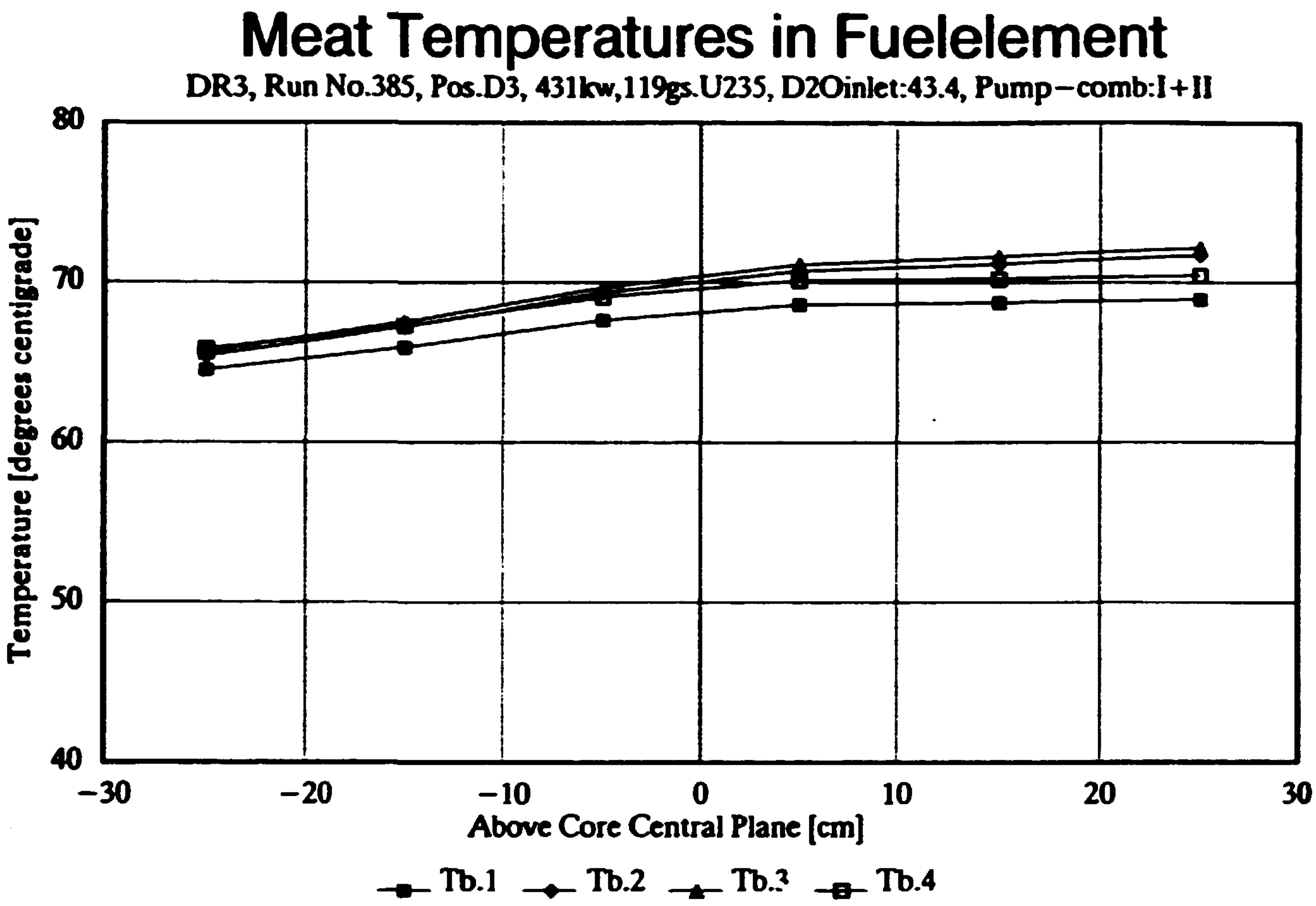
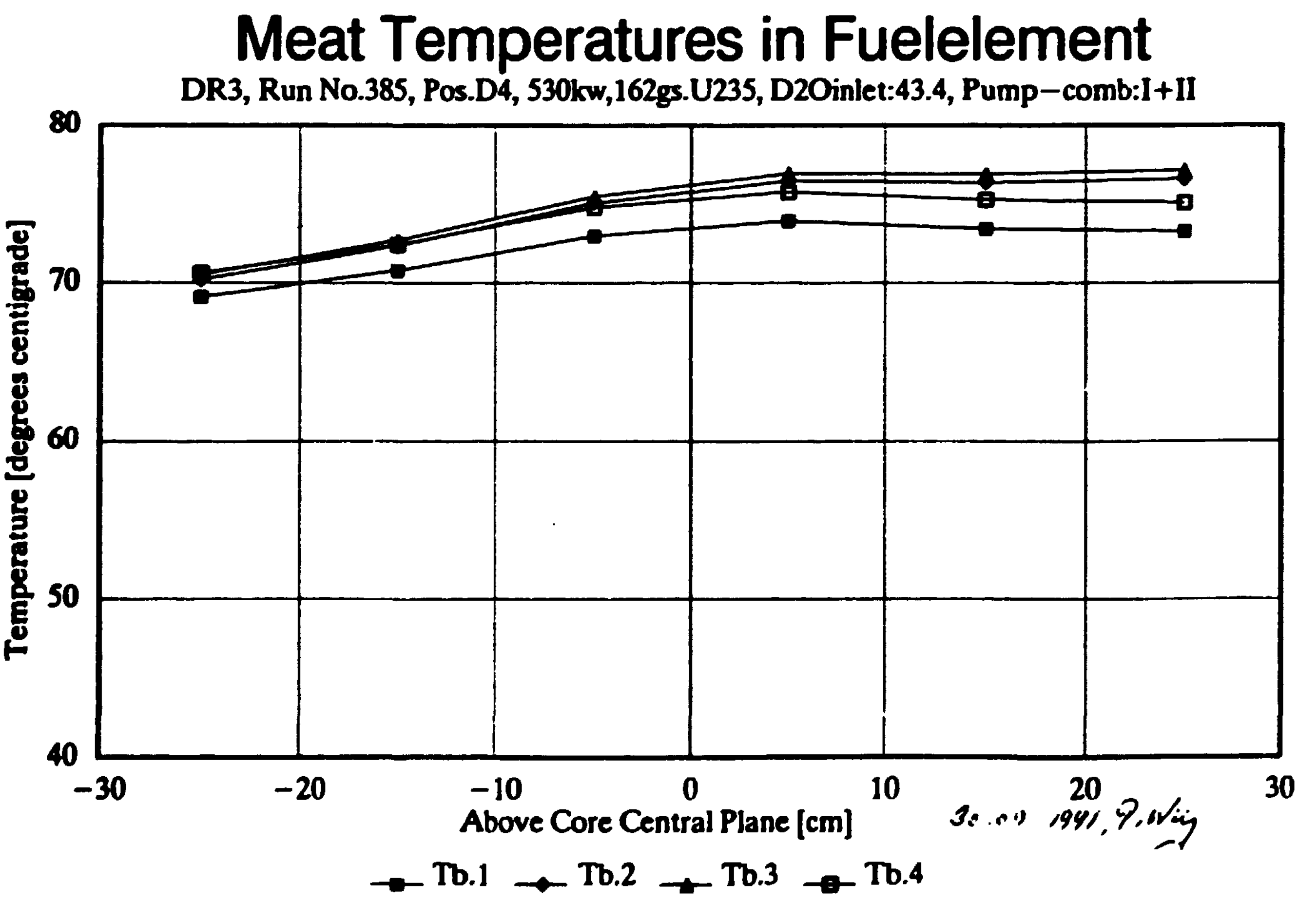


30.09 1991. P. Wey

A2/10





30.09 1991, [illegible]

Meat Temperatures in Fuelelement

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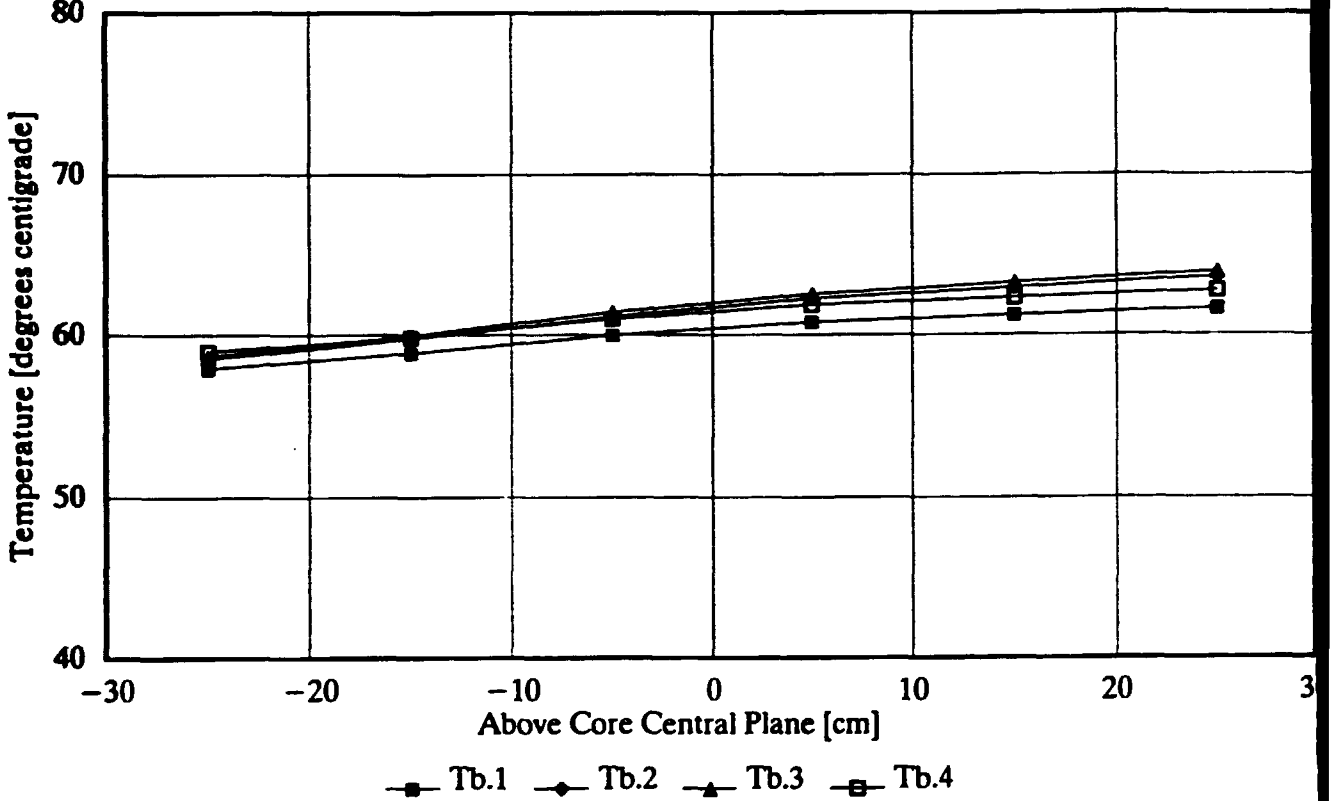

Meat Temperatures in Fuelelement

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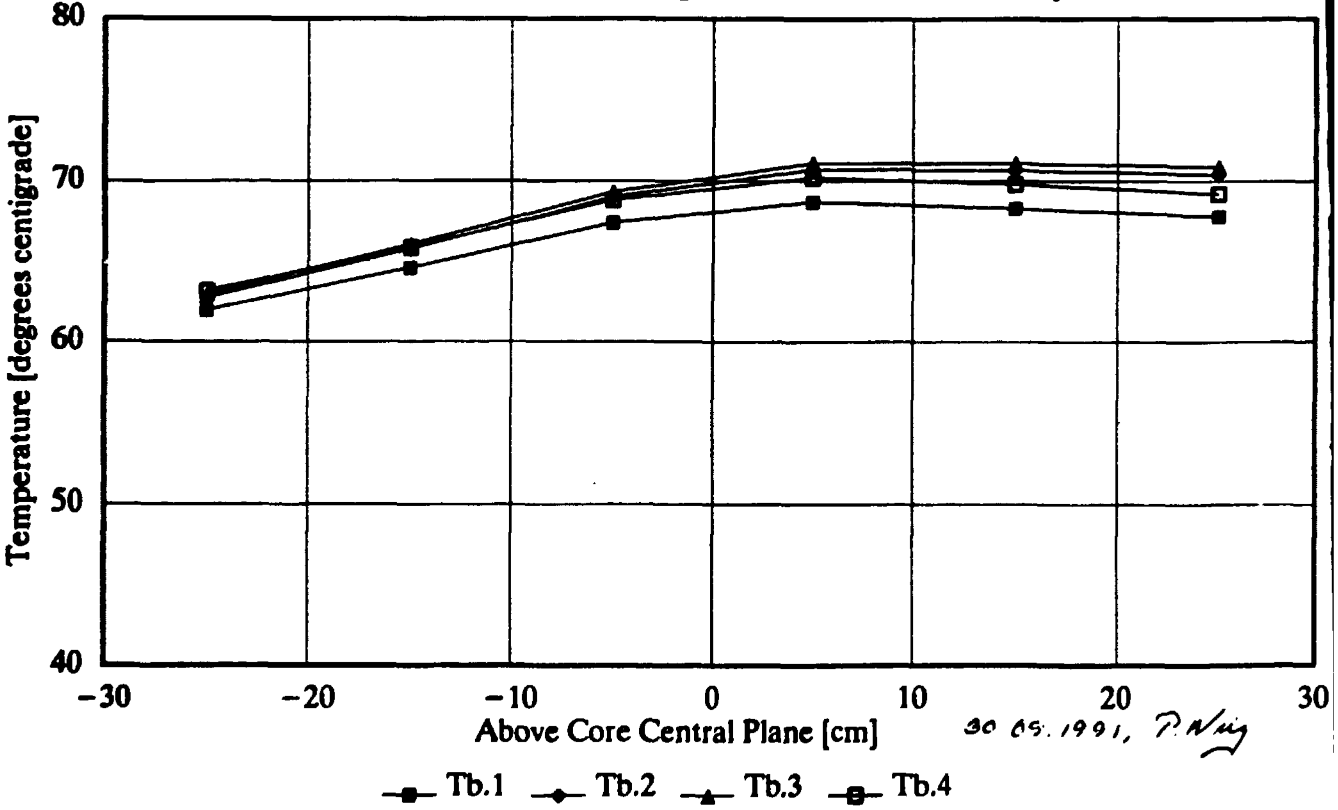

30.05.1991, P.N.

Meat Temperatures in Fuelelement

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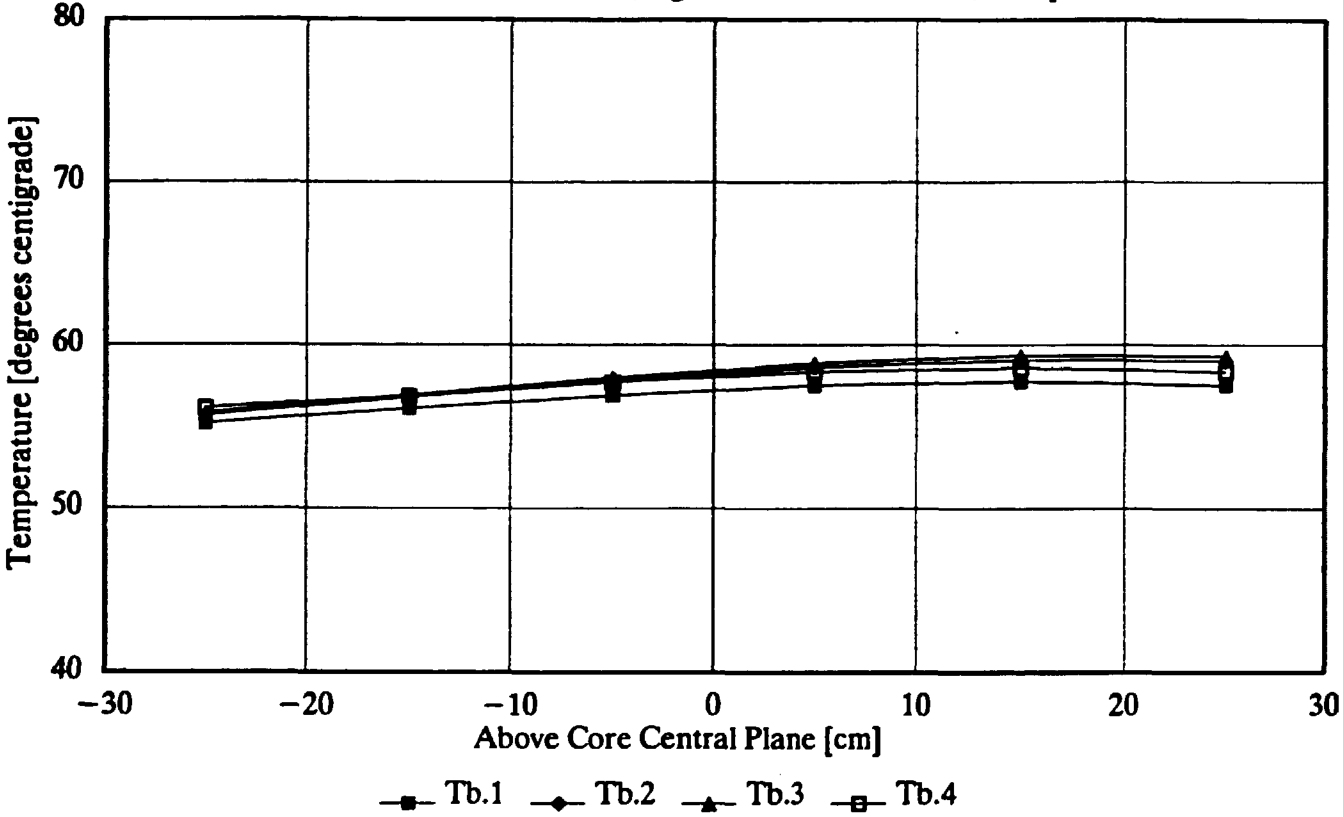

Meat Temperatures in Fuelelement

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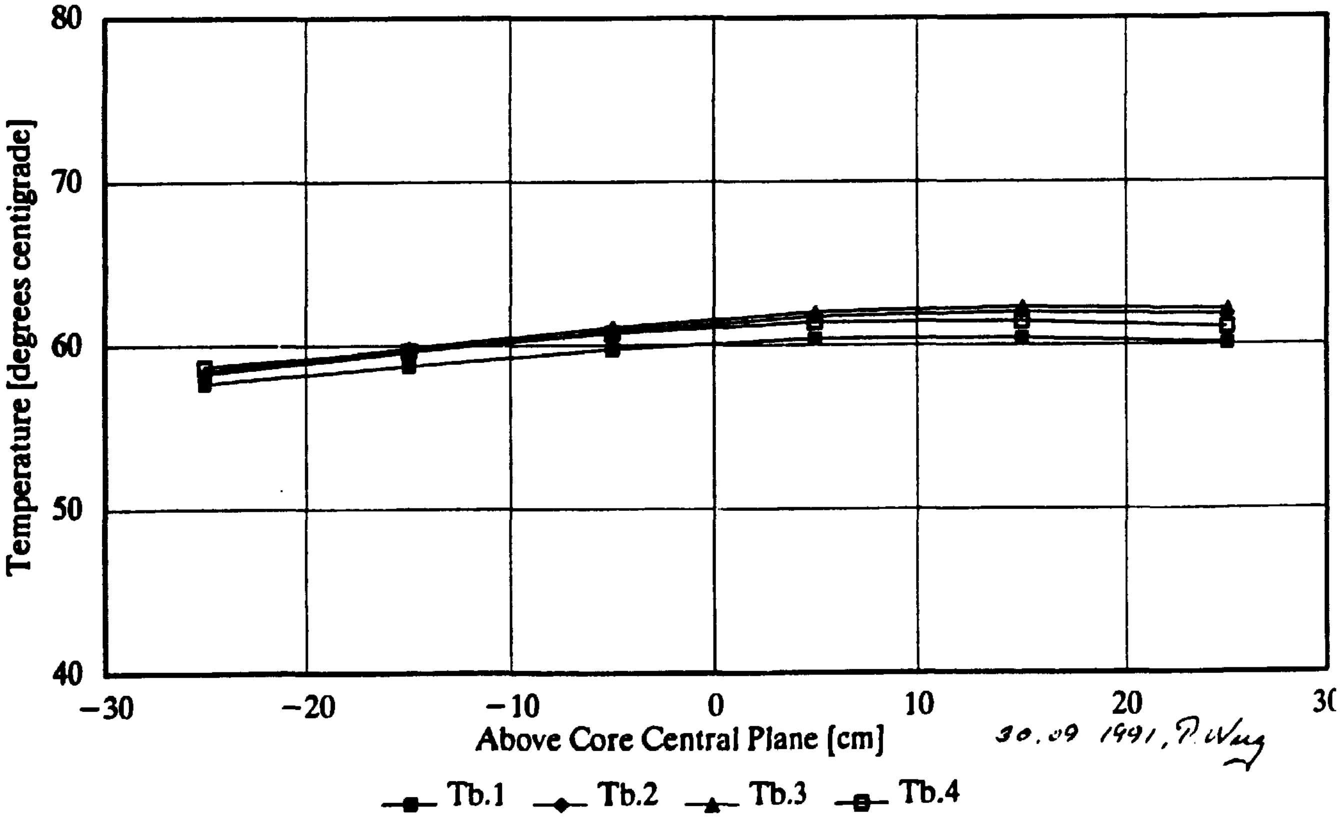

30.09 1991, P. Wang

Meat Temperatures in Fuelelement

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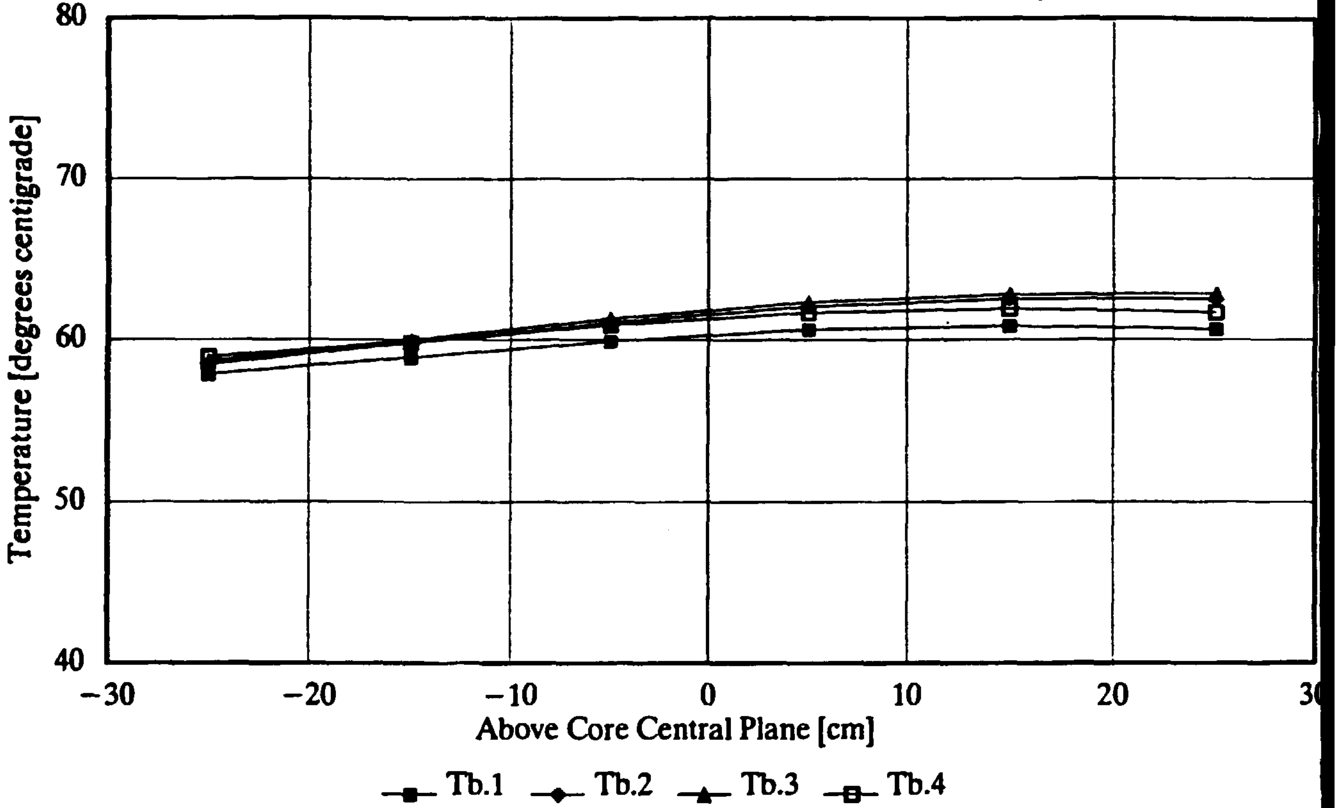

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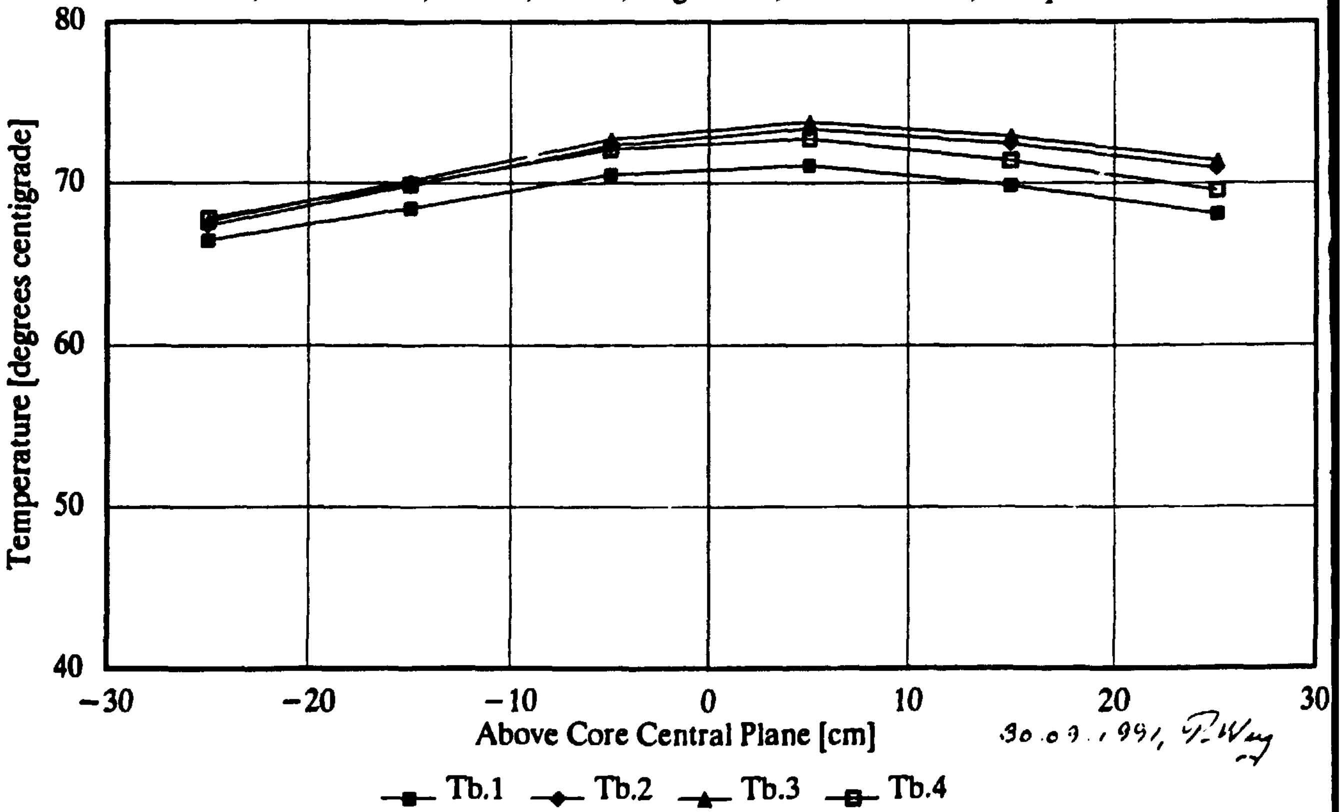

30.09.1991,

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Abstract (Max. 2000 char.)

A calculation method for estimating the axial temperature distributions of each tube in each of the 26 fuel elements of the DR 3 core is described and demonstrated. With input data for fuel element power, D_2O outlet temperature and main D_2O circulator combination, a computer code calculates all important temperatures in the fuel element.

Preface to Second Edition Oct. 1991

The second edition is based on the more reliable thermophysical heavy water properties made available by the investigations of Professor J. Bukovsky (Ref. 2).

The values in table 1 are replaced and a new set of fuel element temperature curves is enclosed as an example of the temperature distributions in a low enriched uranium (19,8% ^{235}U as U_3Si_2).

Descriptors - INIS

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